NASA's Microgravity Science Laboratory:

Illuminating the Future

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acoustic levitation, alloys, combustion, containerless processing, convection, crystals, diffusion coefficient, diffusion flows, electromagnetic levitation, flame(-)balls, flame(s), glasses, IML, International Microgravity Laboratory, ionic metals, laminar combustion, Lewis number(s), Marangoni convection, materials science, materials processing, metallic crystals, metallic liquids, metals, microgravity, overcooling, protein crystallography, proteins, semiconductors, sintering, space-based processing, Spacelab J, Spacelab, Space Station, surface(-)tension(-)driven convection, surface tension, thin films, undercooling, United States Microgravity Laboratory, USML, vapor diffusion

Getting Away To Explore And Build

We often separate ourselves from day-to-day distractions to work more efficiently. Isolation from these events often improves the quality of our work and learning. Scientists, too, often wish to escape the ever-present constraints of Earth's gravity and atmosphere to obtain fresh perspectives on everyday events such as materials processing, heating, and fire safety. Investigators can isolate their experiments on an orbiting spacecraft, where the effects of gravity are almost non-existent. There, in a low-gravity environment, scientists can explore the processes and phenomena behind everyday operations in a way not possible before. Free from the confines of gravity, they can impose precise conditions on experiments to learn more about these phenomena and how they can be controlled.

In many ways, conducting experiments in microgravity can be thought of as taking the cover off a machine to observe its inner workings. Gravity hides many things from investigators: the ways that molten, or liquid, materials solidify; the true structure of complex crystals; and the phenomena that underlie burning (combustion). Microgravity, however, offers scientists a clear view of the processes and conditions that determine the internal structure of a solidifying material and the opportunity to obtain a more even distribution of the ingredients of that material; the chance to grow crystals with almost perfect structures undamaged by the effects of gravity; and a glimpse of the minute forces and occurrences that lie at the heart of a flame.

Free from the effects of gravity, scientists can explore processes in a way not possible on Earth.

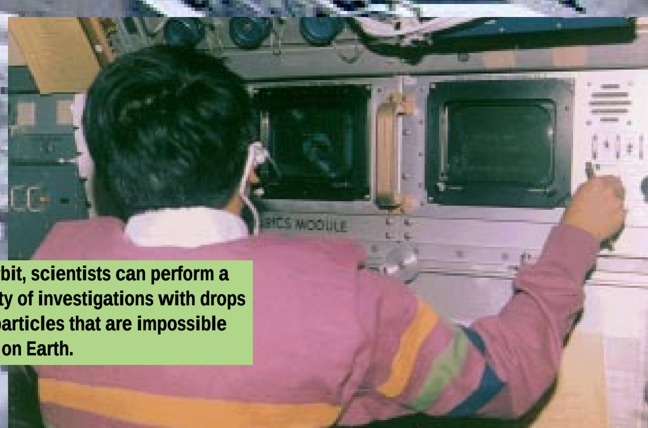
The microgravity environment available in orbit allows scientists to study a variety of biology and biotechnology issues.

For very short periods of time, microgravity can be created on Earth. Experiments can be placed in containers and dropped down tubes or chutes in drop towers to a cushioned landing. These very short periods of microgravity, measured in fractions of seconds to a few seconds, often are sufficient to test theories or equipment designs. The National Aeronautics and Space Administration (NASA) uses drop towers and drop tubes at Lewis Research Center in Ohio and Marshall Space Flight Center in Alabama for these purposes. By flying aircraft in a careful series of roller-coaster-like arcs, brief periods of microgravity — alternating with periods of increased gravity — can be produced. These somewhat longer periods of microgravity, usually 15 to 60 seconds, are suitable for conducting some experiments, for verifying that experiments and hardware will work in microgravity, and for helping train astronauts to work in the absence of gravity. NASA has two planes dedicated to this purpose: a KC-135 weightless training aircraft stationed at Johnson Space Center in Texas and a DC-9 microgravity platform stationed at Lewis Research Center. Sounding rockets, small sub-orbital rockets, launched from NASA's Goddard Space Flight Center Wallops Island facility in Virginia, provide longer periods of microgravity — approximately 4 to 6 minutes. These payloads arch as high as 250 km above Earth's surface before parachuting down to be recovered. The microgravity environment required for long-term investigation and experimentation simply is not available on Earth. Only in space can this unique environment be maintained for the length of time needed by scientists.

Sounding rockets, such as this Black Brant rocket being launched from NASA's Wallops Flight Facility, can provide short periods of microgravity for small payloads.

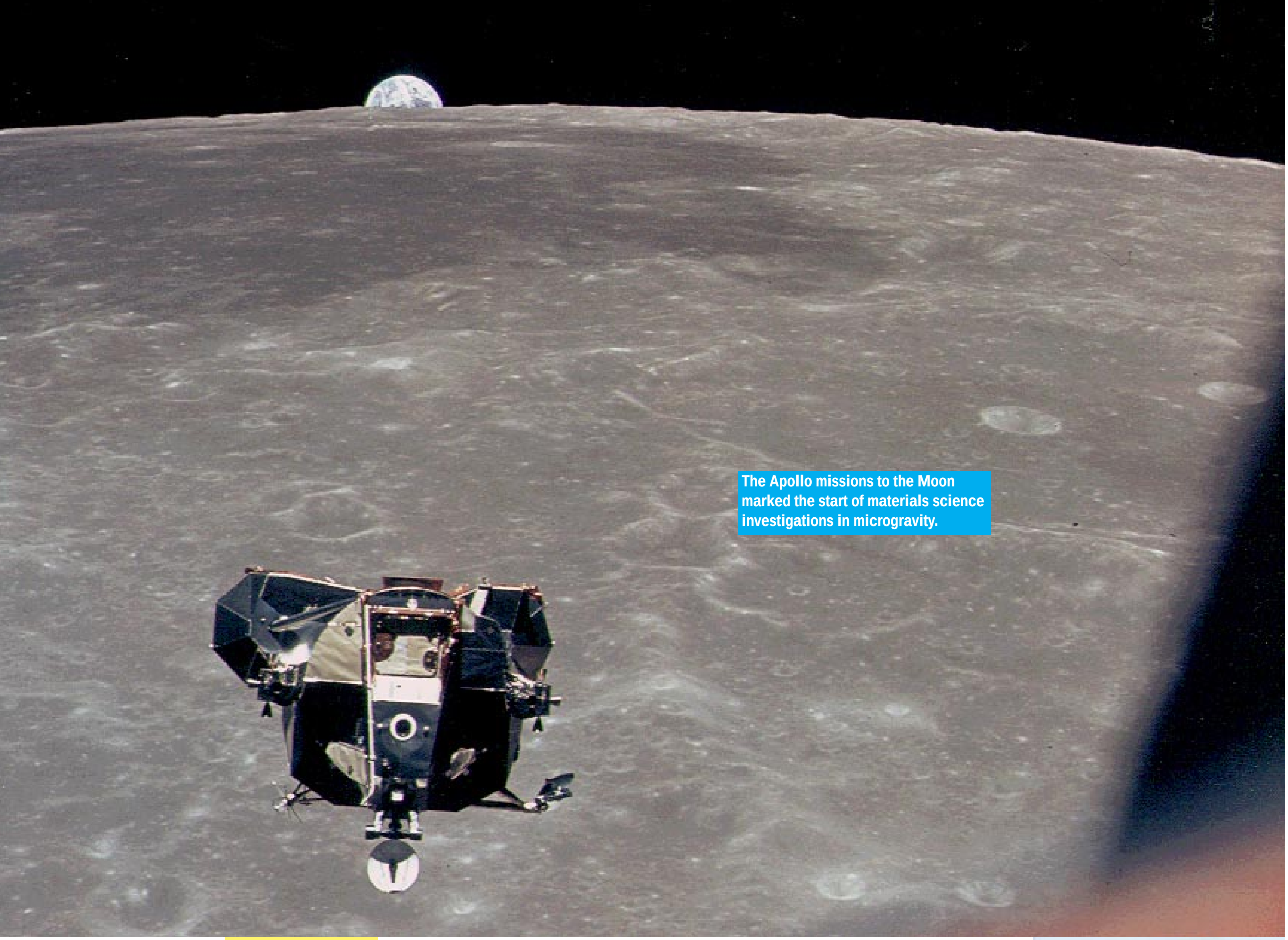
On Earth, drop tubes can provide extremely short periods of microgravity for experimentation.

Brief periods of microgravity, alternating with periods of increased gravity, are created on aircraft flying special trajectories.



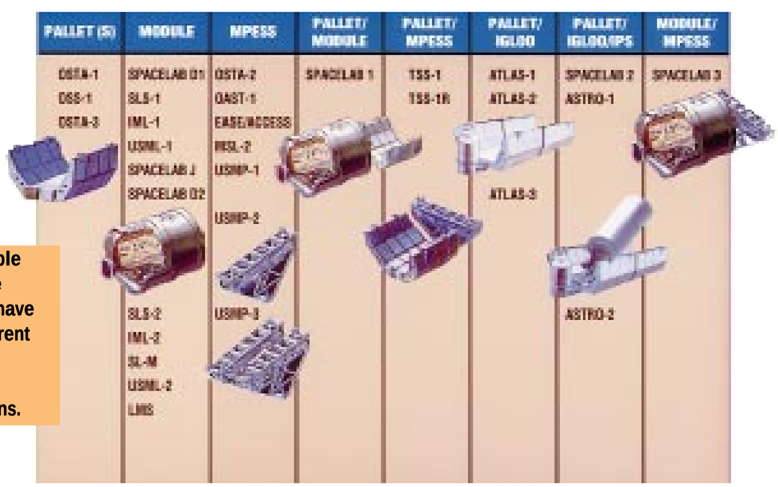
On orbit, scientists can perform a variety of investigations with drops and particles that are impossible to do on Earth.

Getting Away To Explore And Build



The Apollo missions to the Moon marked the start of materials science investigations in microgravity.

The Apollo program provided the first opportunity for extended experimentation in microgravity. The various materials science and life sciences investigations on these flights to and from the Moon laid the groundwork for the first long-term experiments on Skylab, America's first space station.



The interchangeable components of the Spacelab system have been used in different configurations to support more than 25 science missions.

Skylab was an important stepping-stone to modern microgravity sciences. Investigators were able to gather data on changes to the human body that were caused by living in weightlessness for extended periods of time — from 28 to 84 days. They also were able to study the effects of microgravity on other organisms, species ranging from spiders to plants. Experiments in materials science also benefited from these longer periods of microgravity. Samples of metallic crystals, alloys, semiconductors and other materials were produced, and investigators were able to learn much about designing and building specialized hardware for conducting experiments.

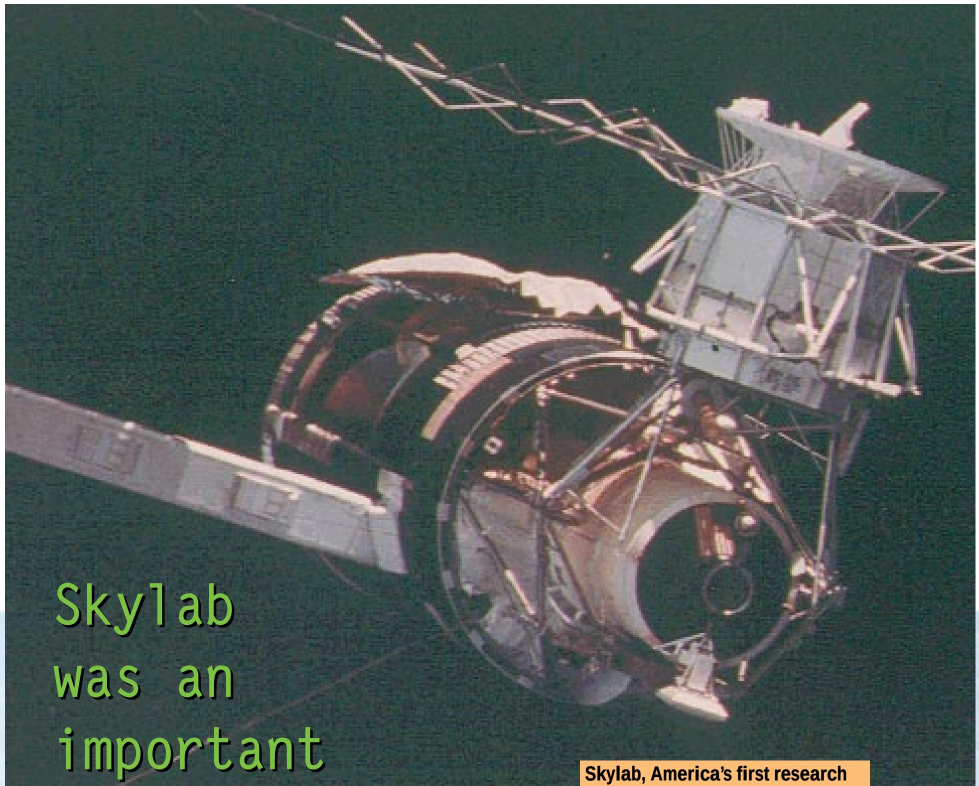
The knowledge gained on Skylab led to the development of new facilities and experiments designed for use on the Space Shuttle, particularly for use in its Spacelab payload.

Spacelab, a joint venture of the European Space Agency (ESA), a consortium of 14 European countries sponsoring space research and technology, and NASA, is the first major international cooperative space effort. It has allowed investigators representing approximately 20 countries to conduct more than 500 experiments in the fields of materials science, life sciences, astrophysics, space technology, and atmospheric and plasma science to be conducted on 30 missions.

Spacelab is a system of interchangeable pressurized laboratory modules, exposed pallets, and complementary structures that fit in the Shuttle's payload bay. The different components can be arranged to provide the best possible laboratory for a given set of experiments. Investigations have been conducted from this outstanding science platform for as long as 16 days, laying the groundwork for operations on Space Station, much the same way the investigations on Skylab formed a basis for Spacelab programs.

Because the International Space Station will be on orbit continuously, it will allow scientists to conduct new experiments for longer periods of time than are possible with Spacelab. From this platform, the opportunities for expanding our knowledge of the Universe and how it works are almost unlimited. Today's Spacelab is providing the bridge needed to develop the more mature microgravity science investigations and hardware that the Space Station will support. Flying on Space Shuttles using the Extended Duration Orbiter package (equipment that allows missions to stay on orbit for up to 3 weeks), Spacelab is providing the opportunity to test Space Station operations and hardware. In addition, the research conducted as part of these operations will provide an extra boost to research planned for Space Station.

The Space Station will use different hardware than Spacelab in almost every respect. Even the way this hardware will be installed is different. Spacelab equipment is loaded into racks and connected to the various power, data, and supply systems from the rear.

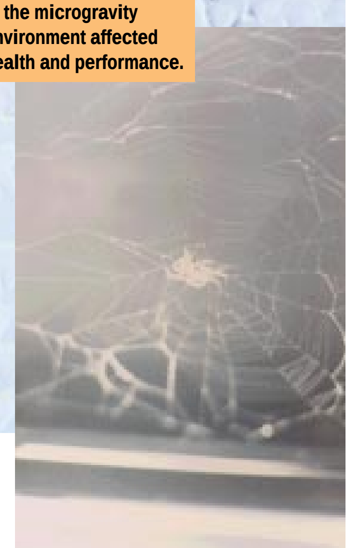


Skylab, America's first research station in space, provided the first opportunity to perform long-term investigations in microgravity.

Skylab was an important stepping-stone to modern microgravity sciences.

The data gathered during Skylab missions on changes to the human body caused by the microgravity environment have provided the foundation for current and future investigations.

Humans were not the only creatures studied to determine how exposure to the microgravity environment affected health and performance.



Getting Away To Explore And Build

Space Station hardware, on the other hand, will be loaded into a new type of rack from the front, and all connections will be made in the front. This makes it easier and more cost effective to upgrade and replace equipment. The new racks, experiment hardware, and procedures need to be tested before the Space Station is built.

The Microgravity Science Laboratory (MSL) is a key component of the bridge between present Spacelab and future Space Station operations. Bringing together many of the major Space Station partners in a joint venture designed to model future operations, MSL builds on the cooperative and scientific foundation of the International Microgravity Laboratory missions (IML-1 and IML-2), the United States Microgravity Laboratory missions (USML-1 and USML-2), Spacelab J, and the German Spacelab missions (D-1 and D-2). It also brings together international academic, industrial, and governmental partners to obtain maximum benefit and results. MSL uses new and existing facilities to expand previous research and begin exploration in new directions. In addition, it is serving as a test-bed for new procedures designed to place scientific payloads into orbit in a shorter amount of time than previously possible.

USML-1

IML-1

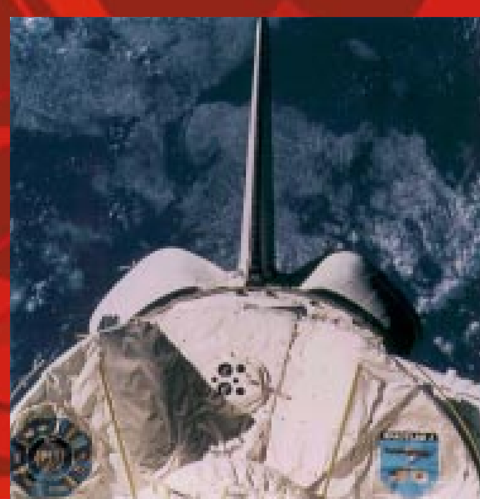
Today's Spacelab is providing the bridge to the Space Station.

D-1

D-2

USML-2

IML-2



SLJ

Doing More In Less

When looking at television images from the Spacelab module or the Space Shuttle, we often see the crew floating around, performing the investigations that lie at the heart of each mission or, in more playful moments, chasing after candy or balls of liquid hanging in mid-air. Often, this apparent weightlessness is incorrectly referred to as "zero-g" or the absence of gravity. More appropriately, the condition experienced by the crew and experiments orbiting Earth is called microgravity. But what is microgravity?

NASA uses the term microgravity to describe a condition of free-fall within a gravitational field in which the weight of an object is significantly reduced compared to its weight at rest on Earth. The effects of gravity are reduced by allowing an object to fall. As it falls, the object and anything in it fall with an acceleration caused almost exclusively by gravity, so they "float" in relation to each other as if there were no gravity. This reduced-gravity environment can be created only by free-fall because, to find microgravity conditions similar to those experienced by astronauts orbiting the Earth, one would have to travel more than 6 million kilometers into space — 17 times farther away than the Moon. At the altitude the Space Shuttle orbits (140 to 250 km), the pull of Earth's gravity is still almost as strong as it is at ground level. If it were possible to drop a ball from the top of a tower that reached to the same altitude at which the orbiter circles Earth, the ball would fall toward Earth just as it would if it were dropped from a tall building. The Shuttle, however, is falling around Earth in such a way that it never hits the ground, allowing its contents and passengers to experience microgravity for as long as the Shuttle is in orbit. While in free-fall, the Shuttle and its contents are "isolated" from the effects of Earth's gravity. Aboard the orbiter, even the heaviest objects no longer fall "down," and spilled liquids form balls that float rather than form puddles that flow across the floor.

Often, the crew playfully show the effects of microgravity to viewers on the ground using food, such as this demonstration during the Spacelab J mission by Astronaut Jan Davis.

The free-fall environment of the orbiting Space Shuttle provides unique opportunities to researchers. Subtle and complex phenomena, normally hidden by the stronger force of gravity, can be revealed for detailed study. For example, the way a fire starts and spreads can be studied without the interference of gravity, giving scientists a better understanding of the processes involved and, perhaps, leading to improved fire safety. Mixtures that separate on Earth because of the different densities among their components can be mixed evenly and processed in microgravity. This allows scientists to study the processing of such materials and to create advanced materials for study and comparison.

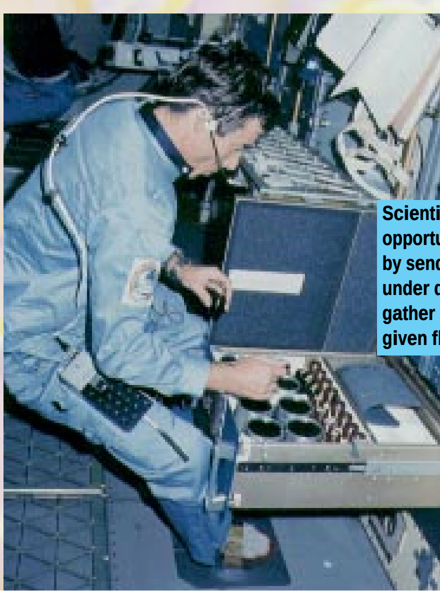
Without the pushing, pulling, and other effects of gravity, more perfect inorganic crystals can be produced, which may eventually lead to the creation of advanced computer chips and semiconductors. The growth of near-perfect protein crystals will enhance our understanding of protein molecular structures and may speed the development of improved drugs. Also, scientists can use the microgravity environment to learn how the presence or absence of gravity affects living organisms. This will aid long-term space efforts and also will provide a better understanding of life on Earth by allowing scientists to study biological processes and phenomena impossible to study in gravity.

While in free-fall, the Shuttle and its contents are "isolated" from the effects of Earth's gravity.

On Earth, gravity can cause some products to pick up imperfections or impurities during processing. In microgravity, scientists can reduce or eliminate many of these problems. Japan's first scientist astronaut in space, Dr. Mamoru Mohri, is observing a sample being processed in a Spacelab module as part of investigations into materials processing in microgravity.

In microgravity, liquids do not spill to the floor or form drops. Instead, they form into balls such as this almost perfectly spherical drink of juice that Dr. Leroy Chiao is preparing to pull into a straw.

To work in microgravity, crewmembers have to use handholds and foot restraints to do even simple operations. For example, if a crewmember were to turn a switch without holding onto something, the crewmember would turn instead of the switch.



Scientists try to make the most of each opportunity to experiment in microgravity by sending up multiple samples, processed under different experiment conditions, to gather as much data as possible on any given flight.

Microgravity in Gravity

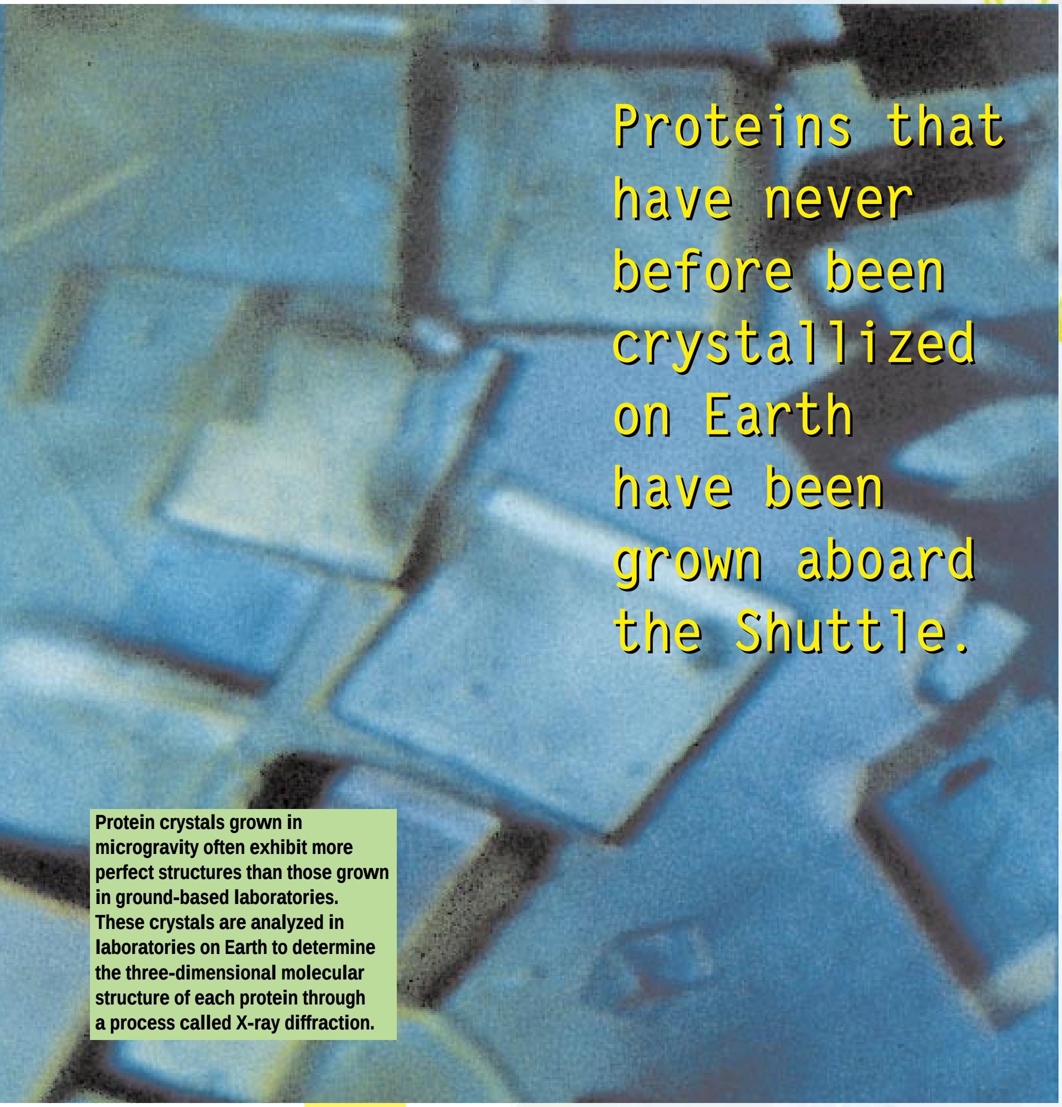
The continuous free-fall experienced by the Shuttle is possible because the orbiter is at the right altitude and speed to cause its “fall” to match the curvature of Earth’s surface. An easy way to visualize what is happening is by doing the same kind of “thought experiment” that Sir Isaac Newton did in 1686.

Newton expanded on his conclusions about gravity, imagining how an artificial satellite could be made to orbit Earth. He envisioned a very tall mountain extending above Earth’s atmosphere so that friction with the air would not be a factor. He then imagined a cannon at the top of that mountain firing cannonballs parallel to the ground. As each cannonball was fired, it was acted upon by two forces. One force, the explosion of the black powder, propelled the cannonball out from the muzzle. If no other force were to act on the cannonball, the shot would travel in a straight line and at a constant velocity. But Newton knew that a second force would act on the cannonball: the presence of gravity would cause the path of the cannonball to bend into an arc ending at Earth’s surface.

Newton described how cannonballs would travel farther from the mountain if the cannon were loaded with more black powder each time it was fired. With each shot, the path would lengthen and soon the cannonballs would disappear over the horizon. Eventually, if a cannonball were fired with enough energy, it would fall entirely around Earth and come back to its starting point. The cannonball would begin to orbit Earth. Provided no force other than gravity interfered with the cannonball’s motion, it would continue circling Earth in that orbit.

The Shuttle can be thought of as the cannonball. It is launched with enough speed and in such a path, known as a *trajectory*, that it constantly falls around Earth. Because the Space Shuttle is in continuous free-fall and upper atmospheric friction is extremely low, a microgravity environment is obtained.

The Structures of Life



Proteins that have never before been crystallized on Earth have been grown aboard the Shuttle.

Protein crystals grown in microgravity often exhibit more perfect structures than those grown in ground-based laboratories. These crystals are analyzed in laboratories on Earth to determine the three-dimensional molecular structure of each protein through a process called X-ray diffraction.

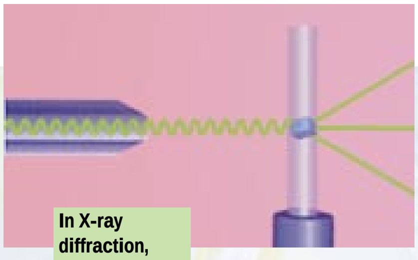
Imagine knowing everything about people or things from the moment you encounter them, including exactly how they will react in any given situation. Doctors would like to have such an understanding about how various diseases, viruses, and drugs will react or work so they can treat a variety of illnesses more effectively. By the same token, farmers and scientists would like this information about viruses and other diseases that affect plants.

While it may never be possible to have such knowledge about human beings, it is possible to develop a better understanding of various diseases through research known as protein crystallography. Proteins are essential components of all living cells and serve many different functions. For example, some proteins make it possible for red blood cells to carry oxygen throughout the body. Other proteins help transmit nerve impulses so we can hear, smell, and feel the world around us, while still others play a crucial role in preventing or causing disease. Proteins are a large group of organic compounds (those that contain carbon) that also usually include atoms of oxygen and hydrogen and may contain sulfur and other elements. Proteins are arranged in one or more chains of amino acids, organic compounds containing nitrogen hydride (NH_2).

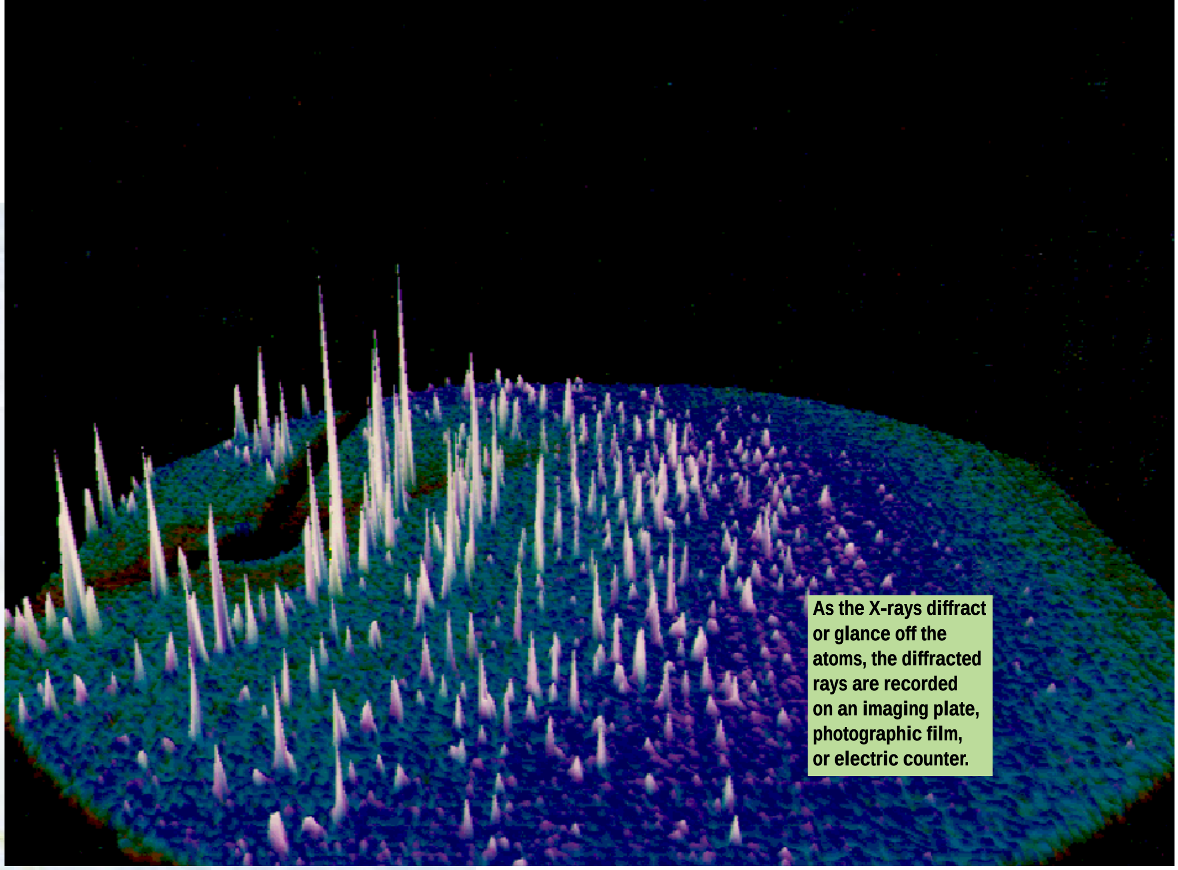
If scientists can decipher the exact structure of a given protein, they can determine how it binds with other proteins to perform its specific function. For example, by knowing the exact structure of a protein involved with digestion, investigators can determine why it is attracted to a specific nutrient and how it breaks that compound apart. By studying a protein that is part of a virus, they can learn how that virus attacks plants or animals.

The difficulty is determining the exact structure of a selected protein. To do this, scientists must grow near-perfect crystals of that protein. These crystals can reveal the three-dimensional molecular structure of a protein, which determines how the protein works.

While some proteins can be crystallized quite easily on Earth, others cannot be because of the force of gravity. Gravity works against the formation of perfect crystals of any substance. By pulling down at the crystal as it forms, gravity distorts the crystal's shape, causes the chemicals that make up the protein to be mixed improperly, and limits the crystal's size. By growing protein crystals in microgravity, investigators can grow near-perfect crystals, which may be larger than those grown on Earth and easier to analyze.



In X-ray diffraction, the crystal is subjected to a beam of X-rays, which are scattered in a regular manner by the atoms in the crystal.

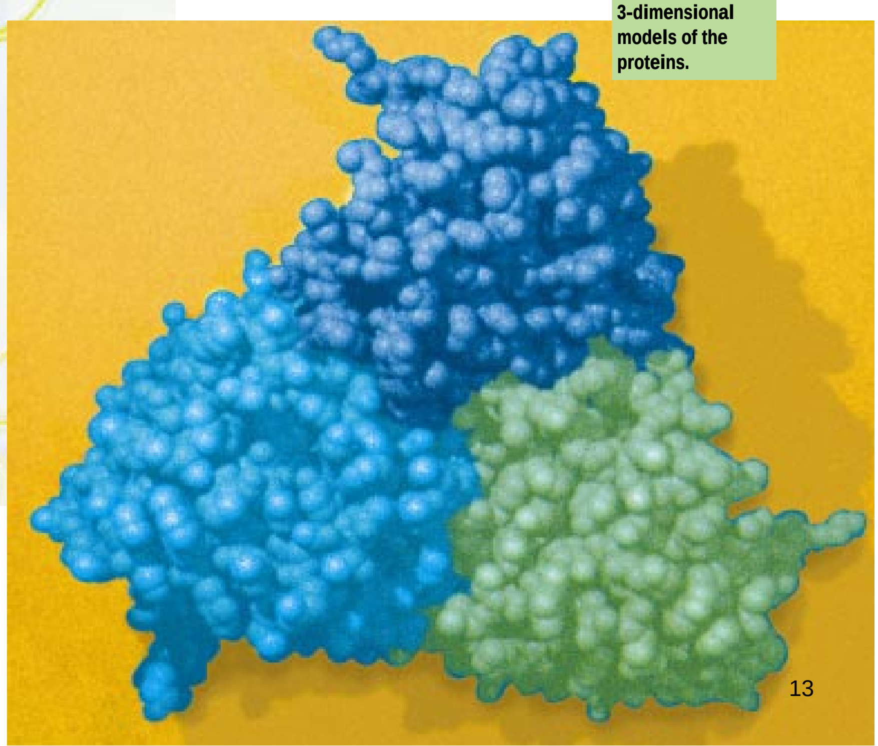


As the X-rays diffract or glance off the atoms, the diffracted rays are recorded on an imaging plate, photographic film, or electric counter.

Many proteins that have never before been crystallized on Earth have been grown aboard the Shuttle. Equally important, scientists have been able to grow different forms of some of these proteins. A good example of this took place on the USML-1 mission when Payload Specialist Dr. Larry DeLucas, a protein crystallographer, was able to grow a particular form of the protein Factor D that he had not been able to obtain during 9 months of ground-based experimentation. This protein is of interest because it can be used in the design of future drugs.

Three protein crystal growth experiments are scheduled for MSL-1. The Protein Crystal Growth Using the Protein Crystallization Apparatus for Microgravity (PCAM) experiment will grow large quantities of various proteins. The Protein Crystal Growth Using the Second Generation Vapor Diffusion Apparatus (VDA-2) experiment will grow high-quality crystals of various proteins using the vapor diffusion method. The Protein Crystal Growth Using the Hand-Held Diffusion Test Cells (HHDTCs) experiment will grow crystals to investigate differences in the processes in microgravity from those on Earth and to refine the cell design of the Observable Protein Crystal Growth Apparatus (OPCGA). Marshall Space Flight Center in Huntsville, Alabama, is NASA's Center of Excellence for protein crystal growth.

Computers perform precise measurements of the intensity of X-rays scattered by each crystal, helping scientists map the probable positions of the atoms within each protein molecule.



From the X-ray diffraction data, scientists can develop computer-generated 3-dimensional models of the proteins.

A Light In The Darkness

We are familiar with combustion, the process of burning; however, we rarely stop to think that burning is a very rapid, often complex, chemical process involving a fuel (the substance that burns or undergoes a chemical change), an oxidizer (a source of oxygen, which is required for combustion to occur), and a source of ignition. When all three components come together in the right manner, a flame is produced. Provided there is a source of ignition, a sufficient supply of oxygen, and a fuel (solid, liquid, or gas), combustion can occur even underwater or in space.

In the simplest terms, combustion occurs whenever oxygen atoms rapidly combine with the atoms of a fuel. A good example of this is the burning of coal, which is made of carbon. With the application of sufficient heat, oxygen atoms in the air combine very rapidly with the carbon atoms in the coal, creating carbon dioxide and releasing large amounts of heat (energy) during the process.

Combustion is, however, rarely this simple and straightforward. For example, coal has elements in addition to carbon that combine with oxygen during burning and produce products other than carbon dioxide.

A vital process that has been the subject of extensive research for more than a century, combustion accounts for approximately 85 percent of the world's energy production — and a significant percentage of the world's atmospheric pollution. Combustion plays a key role in processes involved in ground transportation (the internal combustion engine), spacecraft propulsion (solid rocket motors and liquid fuel engines), aircraft propulsion (jet and internal combustion engines), and hazardous waste disposal (through incineration of the waste).

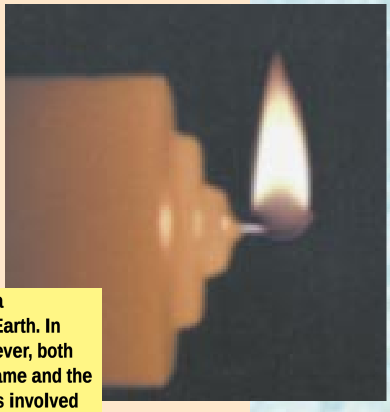
Despite many years of vigorous study, however, we have only a limited understanding of many fundamental combustion processes, including how pollutants are formed by combustion. Gravity limits studies on Earth by masking many subtle phenomena with buoyancy-induced flows and sedimentation. In the presence of gravity, buoyancy-induced flows are created in fluids (liquids and gases) by heating. When heat is applied to a fluid, the fluid closest to the heat source becomes less dense and is pushed up by the cooler (more dense) fluid surrounding it. As the less dense fluid rises, it is replaced by the more dense fluid, and a flow is created. To control these buoyancy-driven flows during ground-based experimentation, scientists have to limit the size, scale, and duration of their experiments, thus limiting the investigations that can be studied on Earth.

Sedimentation is similar in that materials of different densities separate in the presence of gravity. Fluids of unequal densities separate into layers, with the heavier materials sinking to the bottom. Stirring, levitation, or other measures are required to counteract this separation. These countermeasures also place limits on Earth-based experiments.

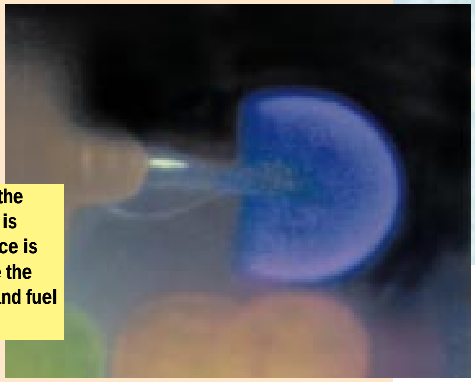
In the microgravity environment, buoyancy-driven flows and sedimentation are reduced or eliminated, allowing scientists to expand the scale and duration of experiments and to study processes and phenomena that may be hidden on Earth.

How Do Candles Burn?

Scientists often use candles to study combustion processes. When candles burn on Earth, the air near the wick heats up, its density decreases, and it rises. Fresh air then is drawn toward the wick, replenishing the oxygen needed for combustion. These air flows are absent in microgravity. As the wick brings fresh fuel to the combustion zone, there are no air currents to bring in fresh oxygen, and product gases like carbon dioxide collect around the wick. As the local oxygen is depleted, combustion slows and the candle is extinguished (or at least burns less vigorously).



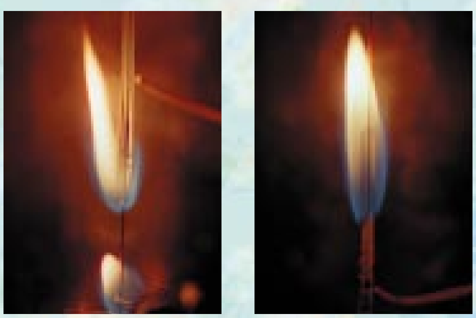
A candle flame is a familiar shape on Earth. In microgravity, however, both the shape of the flame and the physical processes involved in burning are different.



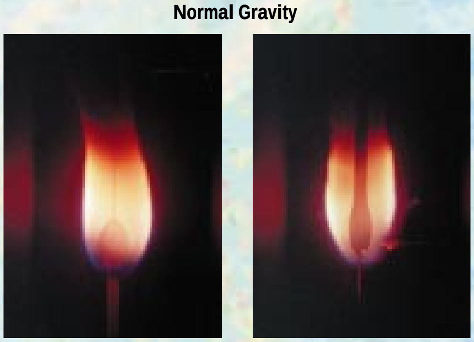
Instead of the familiar tear-drop shape, the shape of a candle flame in microgravity is spherical, just as a drop of water in space is spherical. The flame is smaller because the normal processes that provide oxygen and fuel are almost eliminated.

NASA's combustion science research focuses on six major areas: pre-mixed gas flames, diffusion flames, liquid fuel droplets, fuel dust clouds, the spread of flames along surfaces, and smoldering combustion. The results from experiments in these areas will improve current understanding of how fundamental combustion phenomena are affected by gravity. Also, the results will be used to advance combustion science and technology on Earth and to address issues of fire safety in space. Lewis Research Center in Cleveland, Ohio, is NASA's Center of Excellence for Combustion Science.

The MSL-1 mission will support three combustion investigations. The Laminar Soot Processes investigation will explore soot properties in nonbuoyant laminar jet diffusion flames. The Structure of Flame Balls at Low Lewis-number (SOFBALL) investigation will try to determine if stable, stationary "flame balls" can exist. The Droplet Combustion Experiment will study the processes and phenomena associated with combustion in spherical fuel droplets.

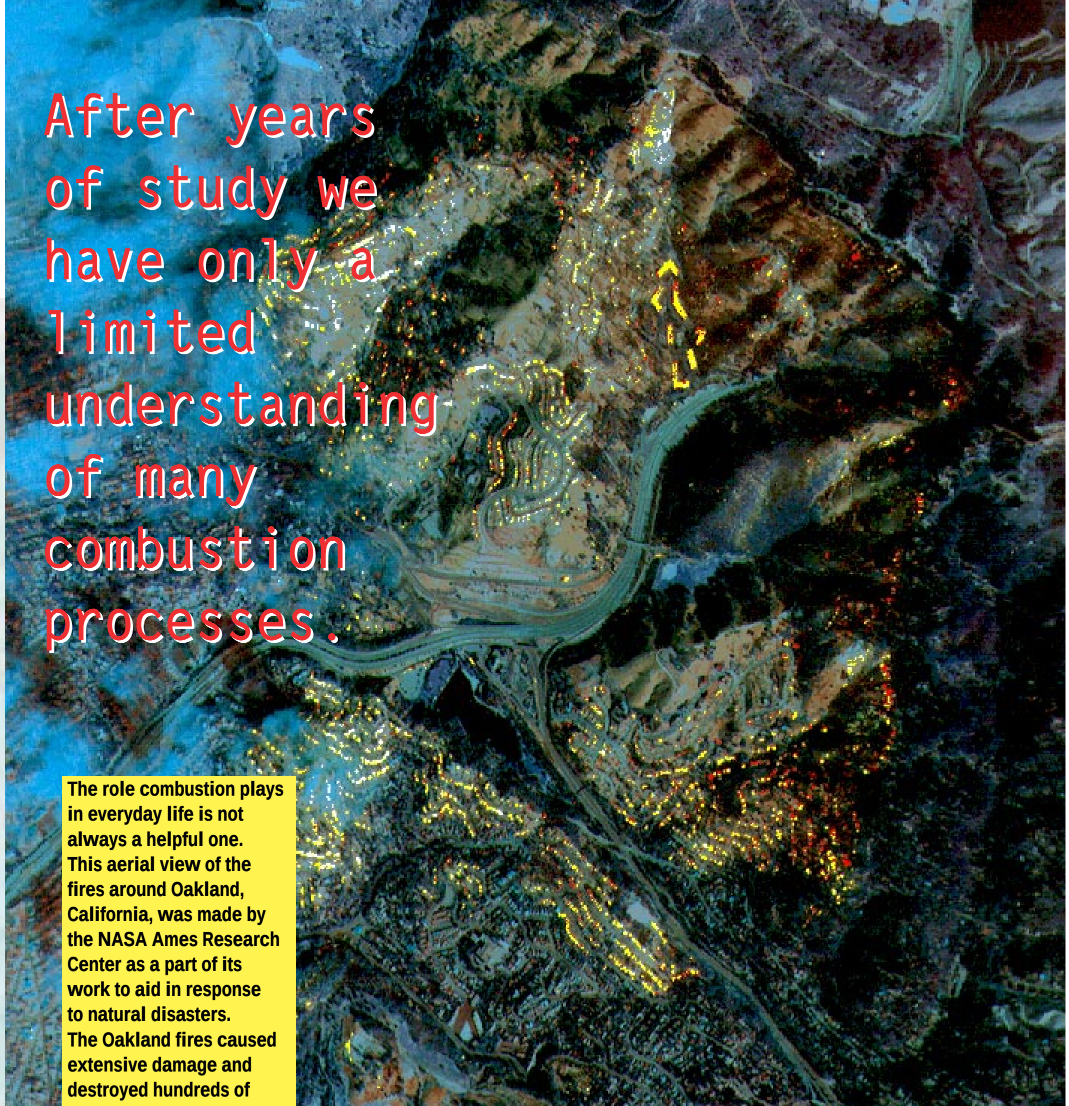


Normal Gravity



Microgravity

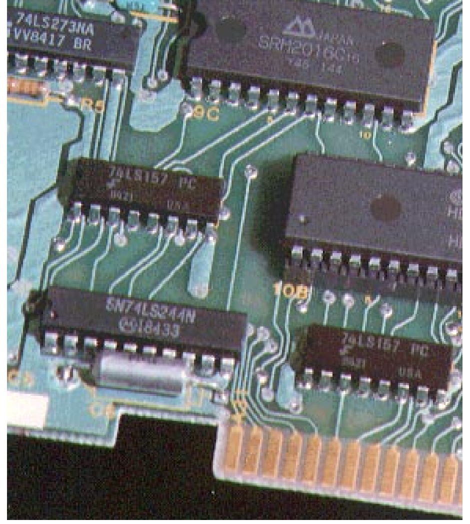
Studying combustion in microgravity will help scientists better understand the processes involved, improving both ground-based combustion uses and ground- and spacecraft-fire safety.



The role combustion plays in everyday life is not always a helpful one. This aerial view of the fires around Oakland, California, was made by the NASA Ames Research Center as a part of its work to aid in response to natural disasters. The Oakland fires caused extensive damage and destroyed hundreds of homes. The hottest parts of the fire show as white or yellow in this image, with fog — rather than smoke — creating the blue clouds seen to the left of the fires.

Using a burner to heat water or cook food is only one of the many positive ways combustion is used in our lives.

Perfecting Structure and Style

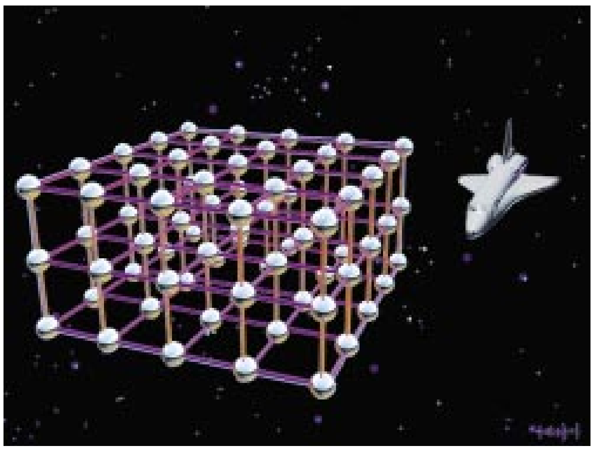


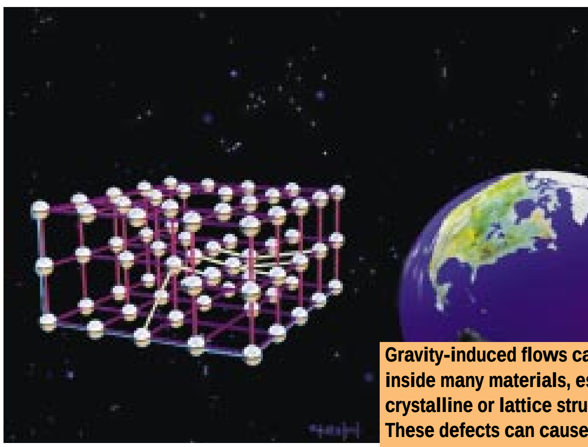
As we go through each day, we may pay little attention to the items we use to do our work, to cook our food, and to communicate with others and even the ones we use for relaxation and play. The tendency is to notice them only when they do not work properly. Yet, most of these items have to be manufactured, making materials science one of the most important fields of scientific research.

The key to materials science research is understanding how the structure of a material forms and how this structure affects the properties of the material. For example, the materials that form "chips" for computers and other electronic devices are crystals. The accuracy of the chip in transmitting electrical impulses, which is paramount to its performing a given task, and its reliability over time depend on the precise alignment of the individual atoms of the material to create a perfect structure.

On Earth, sedimentation and buoyancy cause uneven mixing of the ingredients of the material and can deform the structure as it solidifies. These gravity-induced imperfections limit the usefulness of many electronic materials. Imperfections in the structures of metals and alloys can affect mechanical strength or resistance to corrosion, while similar flaws in glasses and alloys can make them easier to crack or break. Gravity also affects the internal structure of polymers, long chains of organic molecules that form the basis of a range of products from nylon to plastic. Though polymers are not crystals, their long chains of organic molecules often line up with one another — a property known as crystallinity. Controlling this property, and therefore the structure of polymers, could improve a variety of common products and allow polymers to be used in new and important ways.

In microgravity, sedimentation and buoyancy are reduced or eliminated, allowing scientists to study the process of material formation in ways not possible before. Minute forces and phenomena that are overwhelmed by gravity on Earth can be observed and studied. The physical and chemical conditions present during processing can be controlled carefully and can be changed, enabling investigators to learn how these factors affect the final structure of the material. The knowledge gained from these studies will help future microgravity research and material processing efforts and also will be used to improve materials processing on Earth. Marshall Space Flight Center in Huntsville, Alabama, is NASA's Center of Excellence for Materials Science.





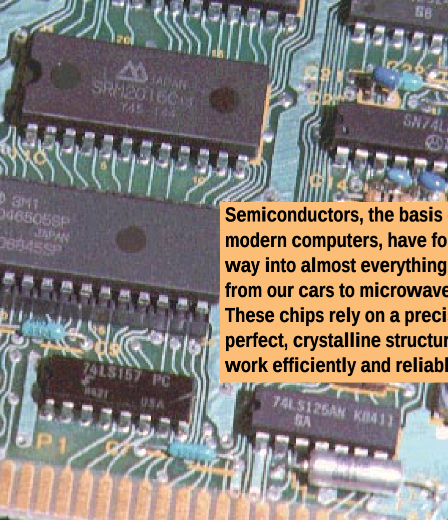
Gravity-induced flows can cause defects inside many materials, especially those with crystalline or lattice structures (bottom). These defects can cause structural weakness or prevent electricity from being transmitted efficiently. They also limit what can be learned about the structure and function of various crystals. Processing in microgravity can result in nearly perfect internal structure (top).

The Four States of Matter

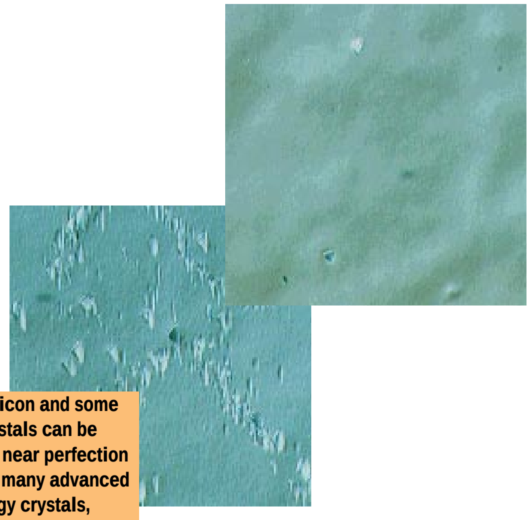
On Earth and in space, matter exists in one of four basic states: solid, liquid, gas, or plasma. We deal with each of these every day. Solid objects form the world around us, from the ground we walk on to the components of televisions and other electronic devices we use for communication and entertainment. Liquids, such as water, make life possible. Gases form the air we breathe and the wind that cools us on a summer day. Plasma, gases whose atoms have lost one or more electrons (becoming ionized) to create a cloud of charged particles, is contained in the long glass tubes of fluorescent lights that provide much of the light in our schools and workplaces.

Matter regularly changes between these states. Water provides an excellent demonstration of this transition. Under typical conditions, water is a liquid and flows through a series of pipes to come out of the tap in a sink. If water is cooled sufficiently, the atoms in it no longer move as fast, and it becomes a solid — ice. If water is heated, it gradually turns into a vapor — steam. If steam is heated sufficiently, it will turn into a plasma when the vaporized water molecules break apart into electrons and ions.

Though there are four states of matter, materials scientists are primarily concerned with two forms of matter: solid and fluid. These are referred to as "forms" because each is composed of one of two types of structures. All solids have either a crystalline or non-crystalline internal structure. Fluids are either liquids or gases but share the common trait that they flow, or move, in response to an outside force such as gravity. Materials processing, and therefore materials science, often changes materials from solids to fluids and back again. The change between forms is a crucial part of materials processing. Understanding the events and changes that occur during these times and how these changes affect properties of materials is an important focus of materials science research.



Semiconductors, the basis of all modern computers, have found their way into almost everything we use, from our cars to microwave ovens. These chips rely on a precise, near-perfect, crystalline structure to work efficiently and reliably.



While silicon and some other crystals can be grown to near perfection on Earth, many advanced technology crystals, such as cadmium zinc telluride, have numerous imperfections, as seen in the lower photomicrograph of a typical Earth-grown crystal. Experimentation in microgravity reduced these imperfections by three orders of magnitude, as shown in the upper photomicrograph of a sample grown on the USML-1 mission.

MSL-1 will feature 19 materials science investigations in 4 major facilities. These facilities are the Large Isothermal Furnace, the EXPRESS Rack, the Electromagnetic Containerless Processing Facility (TEMPUS), and the Coarsening in Solid-Liquid Mixtures (CSLM) facility. Additional technology demonstrations and experiments will be performed in the Middeck Glovebox.

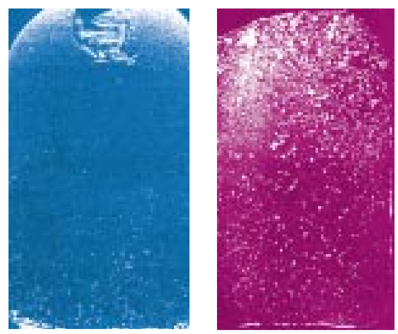
The Fluid Form

Everyone has practical experience with fluids (liquids and gases), and we know intuitively how a fluid will behave under normal circumstances. Steam rises from the surface of a hot spring or a boiling pot, and water spilled on a tabletop runs over, and even off, the surface. Gravity is intricately involved with many of the aspects of fluid behavior on Earth.

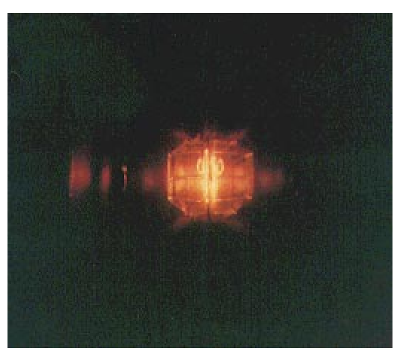
Many of our intuitive expectations about fluids do not hold up in microgravity because the effects of other forces, such as surface tension, control fluid behavior when the influence of gravity is removed. The spherical drops of liquid that form when an astronaut spills water is a familiar example of this phenomena. In microgravity, surface tension on the drops produces almost perfect spheres, while on Earth, gravity distorts them into teardrop shapes.

Differences in fluid behavior on Earth and in microgravity often present engineers and astronauts with practical problems. For example, tanks that contain fluids, such as propellants, must be pressurized so that fluids will flow from the tanks and through pipes. These technical challenges are created by the same phenomena that offer scientists unique opportunities to explore different aspects of fluid physics.

Not only is the knowledge of fluid behavior gained in space important to basic science, but it is also a key to new technologies. The behavior of fluids is at the heart of many phenomena in materials processing, biotechnology, and combustion science. Surface-tension-driven flows, for example, affect semiconductor crystal growth, welding, and the spread of flames on liquids. The dynamics of liquid drops are an important aspect of chemical process technologies and of meteorology. Research conducted in microgravity, such as that being conducted on MSL, will increase our understanding of fluid physics and provide a foundation for predicting, controlling, and improving a vast range of technological processes.



In microgravity, heavier particles are no longer pulled "down" to the bottom of a container, allowing a more even mixing of ingredients as shown in these photographs of an Earth-processed sample (left) and the same mixture processed in microgravity (right).



A sample of glass is melted in a test of acoustic levitation conducted during the brief period of microgravity available during parabolic flight of an aircraft. In microgravity, less force is needed to levitate and control the sample, and processing can continue for long periods of time.

The Solid Form

Just as fluids can be subdivided into liquids and gases, solids can be subdivided into crystalline or non-crystalline (amorphous) forms, based on the internal arrangement of their atoms or molecules.

The most common form of solid is the crystalline form.

The crystalline form includes minerals, such as geodes or quartz crystals; metals, including steel, iron, or lead; ceramics, such as a dinner plate or floor tile; and semiconductors, which are used in televisions or radios. Crystalline solids have a repeating, three-dimensional pattern to their internal structure: the atoms line up on planes that are stacked upon each other.

Crystals typically have different regions, where the planes are lined up in different directions. This is known as a polycrystalline structure, and the individual regions are known as grains. The size and orientation of these grains help determine the strength of a metal or the brittleness of a ceramic. Some materials, such as semiconductors, can benefit from the elimination of all grains but one, producing a single crystal with the constituent atoms lining up on a single set of geometric planes.

Crystals can form in many ways: they can result from freezing liquids, the way ice cubes form; they can precipitate from solution, the way rock candy is made from a sugar solution; or they can condense from vapor, the way frost forms in a freezer. In all of these cases, gravity affects how the crystals grow. By conducting experiments on crystal growth in microgravity, scientists can learn how gravity influences these processes and how crystals grown in microgravity differ from those grown on Earth.

A Bridge To The Future

Space Station: Instead of mere seconds, minutes, or hours in microgravity, investigations on this orbiting platform will have days, weeks, or months of time in this unique environment. Long-term experimentation will be enhanced by onboard analysis, eliminating the need to return samples to Earth, a process which may damage subtle and fragile structures. An X-ray crystallography facility, for example, will allow protein crystals to be analyzed on orbit, at the optimum point in their growth process.

The unparalleled opportunities offered by this orbiting science platform will enhance our understanding of the Universe, while providing information that has down-to-Earth applications. Making the most of this opportunity, however, requires a bridge connecting the foundations that have been laid by Apollo, Skylab, and previous Spacelab missions and the next spacecraft of possibility: Space Station.

The Microgravity Science Laboratory program helps span the gap between what is and what will be. Using Spacelab as a literal transition vehicle, MSL provides the means to test some of the hardware, facilities, and

Opportunities offered by an orbiting science platform will enhance our understanding of the Universe.

When completed, the International Space Station will provide an unparalleled base for a variety of scientific investigations.

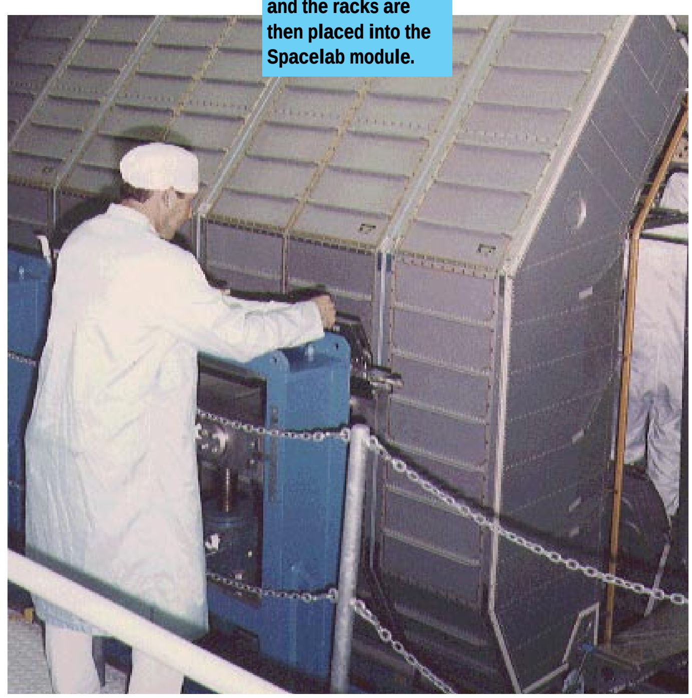
procedures that will be used on Space Station. Almost everything about Space Station will be different from past efforts, from how experiments are developed to the way they will be installed. While ground-based testing and development can help with portions of this process, the best and most cost-effective way to prepare is to try each part of the process during an actual spaceflight.

Spacelab is a very capable platform that provides unparalleled flexibility to investigators because its hardware can be modified or matched to the needs of the experiment. This flexibility, however, results in a relatively lengthy, and sometimes complex, process for combining experiment and facility hardware with the Spacelab and orbiter systems. In contrast, Space Station will challenge investigators to provide experiments that will mate with existing hardware and work within preset resource limits. Also, the time for identifying an experiment and placing it in orbit will change. NASA has reduced the time required for getting selected investigations to orbit from approximately 2 years to 9 months.

Obviously, this new way of integrating investigations and equipment will require new procedures at every step. MSL is providing a real-time test of this new way of performing experiments in space, helping to validate and improve the process.

A key component of these operations is the EXpedite the PRocessing of Experiments to the Space Station (EXPRESS) Rack, which is designed for quick and easy installation of experiment and facility hardware on orbit. While hardware and facilities are integrated into Spacelab racks from the back before the racks are installed in the Spacelab module, Space Station experiments will be placed into EXPRESS Racks from the front. External cables and tubing will then be used to connect the experiment hardware to power, water, and other Space Station resources.

On the first MSL mission, the EXPRESS Rack will take the place of a Spacelab double rack, and special hardware will provide the same structural and resource connections the rack will have on Space Station. During the mission, two payloads will be flown to



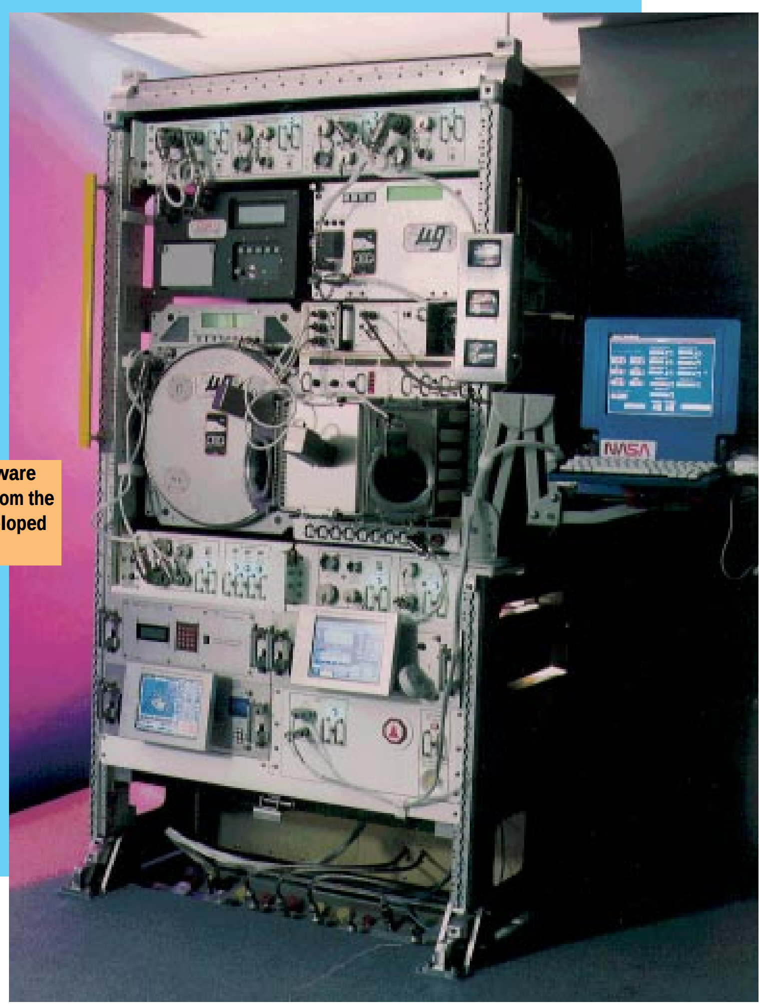
On Spacelab, experiment hardware is loaded into racks, all connections are made in the back, and the racks are then placed into the Spacelab module.

check the design of the EXPRESS Rack hardware and to verify the development and integration processes. To help validate the system, the Physics of Hard Spheres (PHaSE) experiment will require the equivalent of four Spacelab middeck lockers and a Standard Interface Rack drawer. It will use the majority of EXPRESS Rack resources, including power, data, and cooling water. Selection of the second investigation, the Astro/Plant Generic Bioprocessing Apparatus experiment, was postponed until a year before launch to help test the short integration cycle planned for Space Station.

MSL also will refine the use of remote sites for science operations and support. Remote operations have been used on previous Spacelab missions, and remote operations on MSL will make use of previous hardware and facilities. This mission, however, also will involve a new remote operations site in Japan.

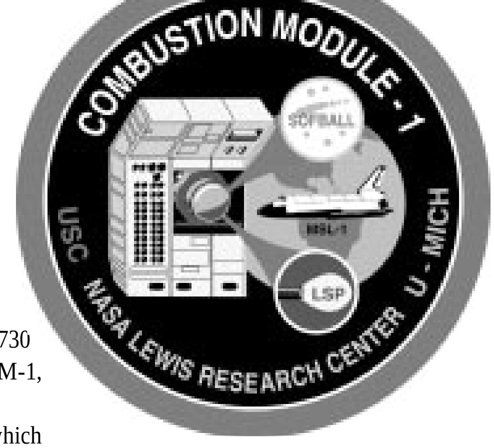
Another advanced operational concept being tested on MSL is the use of "expert" software systems. These systems, which are expected to reduce the number of people required to support Space Station operations, are software packages designed to augment human controllers and provide a rapid response to changes in operations. For example, a software package is being developed to assist the Payload Systems Engineer by gathering data about the unique aspects of each payload or experiment. With this data, the system will be able to supply immediate information about impacts to the operation of each experiment should there be an unscheduled occurrence, such as a change in available resources (electrical power, cooling, etc.) or a need to start or stop an experiment.

By thoroughly testing each of these new procedures, hardware, and systems, MSL is helping ensure that Space Station research has the best start possible. In addition, data and samples from the scientific investigations will provide information needed to ensure mature, long-term research in microgravity.

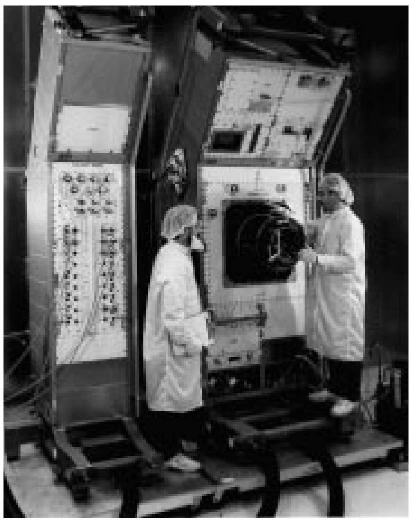


Because experiments and hardware will be loaded and connected from the front, a new rack has been developed and will be tested on MSL.

Combustion Module–1

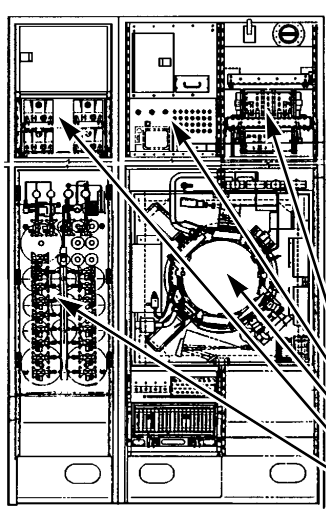


Combustion is the single most important chemical process in our everyday lives. It provides the energy to run our cars, to generate electricity, and to heat our homes during cold winter nights. Despite this and the fact that fire has been a part of human experience from a very early time, scientists still do not have a complete understanding of combustion. Many aspects of this process remain hidden from study behind the curtain of gravity.



By doing research in space, we open the gravity "curtain" and find a microgravity environment that greatly benefits the study of fundamental combustion processes. In this environment, buoyancy-induced flow, the phenomenon that causes warm air to rise, is nearly eliminated; weak or normally obscured forces and flows can be isolated; gravitational settling or sedimentation is nearly eliminated; and experiment time and length scales can be expanded. Unexpected phenomena have been observed in low-gravity experiments, leading to a re-examination of classical theories and the pursuit of new hypotheses. Microgravity combustion research also has direct practical applications in spacecraft fire safety, combustion diagnostics, soot predictions, and combustion system design.

Combustion studies also will be an important part of the scientific research conducted on Space Station. As a part of the preparations for this research, the Combustion Module-1 (CM-1) has been developed by NASA to test hardware and experiment approaches on Spacelab. The key concept CM-1 demonstrates is the accommodation of a variety of combustion experiments through the use of experiment-unique chamber inserts called Experiment Mounting Structures (EMSs). Each investigator's EMS will be installed in the combustion chamber on orbit. For MSL-1, CM-1 will have two investigations: the Laminar Soot Processes (LSP) experiment and the Structure of Flame Balls at Low Lewis-number (SOFBALL) experiment.



CM-1 requires two Spacelab racks, one double and one single rack, with a combined weight of more than 1,600 pounds or 730 kilograms. At the heart of CM-1, the double rack houses the Experiment Package (EP), which contains the 90-liter combustion chamber, the gas chromatograph, and seven cameras. The EP chamber slide rails and quick disconnects enable the crew to insert and connect the EMS for each investigation. Also housed in the double rack are experiment computers and support equipment, including the Video Interface Package (VIP), the Diagnostic Processor Package (DPP), the Dedicated Experiment Processor Package (DEPP), the Exhaust Vent Package (EVP), the Power Distribution Package (PDP), the Experiment Power Switch Panel (EPSP), and the Remote Acquisition Unit (RAU).

The single rack contains the Video Cassette Recorder Package (VCRP) and the Fluid Supply Package (FSP). The FSP contains 20 bottled gases and supplies gas for combustion, combustion chamber purges, soot sampler actuation, chemical diagnostics, on-orbit system leak tests, and pure air in the combustion chamber for science and crew access.

For SOFBALL, 14 bottles contain a range of premixed gases consisting of oxygen, hydrogen fuel, and a diluent. For LSP, two bottles contain the propane and ethylene fuels, and another bottle provides the pure air. The last three bottles are used for other functions listed above. All waste gases flow through the EVP and are vented overboard using the Spacelab vacuum vent system.

The two EMS units will be launched in the Spacelab center aisle stowage containers. The main components of the LSP EMS are a fuel nozzle, a hot wire ignitor, temperature sensors, a radiometer, and soot samplers. The SOFBALL EMS main components include a variable gap spark ignitor, radiometers, and a mixing fan.

The results of CM-1 not only will modify and expand the understanding of complex combustion processes today but also will serve as a test bed for future Space Station combustion research.

CM-1 Capabilities:

- *Pure fuels and premixed fuel-oxidizer combinations*
- *Atmospheres — different pressures at the start of experiments*
- *Imaging systems — video, color and intensified imaging, including digital and analog processing and recording*
- *Temperature, pressure, and radiation measurements*
- *Measurement of soot concentration (soot volume fraction) via laser light extinction*
- *Combustion product analysis — sampling and analysis of gases and soot on orbit, as well as storage for postflight analysis*

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Combustion Module–1

Laminar Soot Processes

Principal Investigator:
Dr. Gerard Faeth,
University of Michigan

Purpose: to extend current investigations on soot properties in nonbuoyant laminar jet diffusion flames to higher pressures; to complete measurements of soot concentrations and structure for various fuels, residence times, and pressures; to develop and evaluate theories of soot production, aggregation, oxidation, and radiative properties; and to assess viability of state relationships for soot volume fractions and temperatures in nonbuoyant flames

Importance: Continuum radiation from soot is the main heat load for combustion components and controls their durability; it is the dominant mechanism for the growth and spread of unwanted fires. Soot and its associated carbon monoxide emissions are objectionable pollutants, with the latter being the primary source of fatalities in unwanted fires.
To improve theoretical models and achieve rational flame structure predictions, scientists must study soot processes in diffusion flames.

Method: Fuel will be ignited in a laminar flame under varying conditions. Imaging systems, lasers, thermocouples, and other devices will be used to gather data on flame shape, the type and amount of soot produced under each set of conditions, and the temperatures of the elements involved. These data then will be analyzed and compared to theoretical predictions.

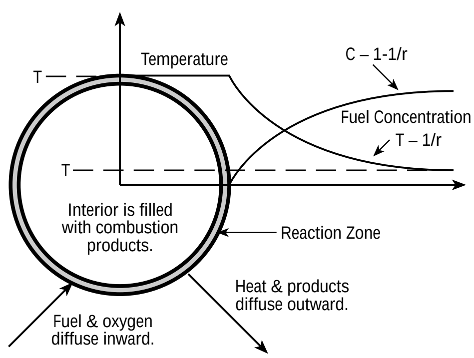
Structure of Flame Balls at Low Lewis-number (SOFBALL)

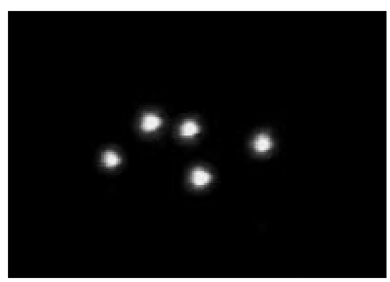
Principal Investigator: Dr. Paul Ronney, University of Southern California

Purpose: to determine if stable, stationary spherical flame structures ("flame balls") can exist; if so, to determine if radiative loss is the stabilizing mechanism; and to determine how mixture properties affect the existence and stability of flame balls

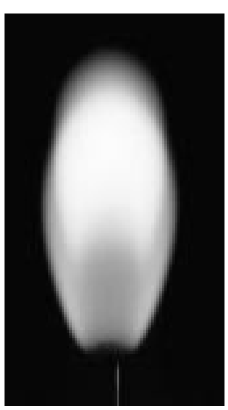
Importance: The mechanisms of flame extinction and stability limits in pre-mixed gases are not well understood. Stationary spherical flames are the simplest interaction between chemical and transport processes, which are the two major elements of the combustion process. Data on these flames would lead to improved theoretical models of near-limit combustion. These, in turn, would enable the development of improvements in lean-burn internal combustion engines, an advancement that holds the promise of providing increased efficiency and reduced emissions, and would lead to improvements in fire safety for mine shafts, chemical plants, and spacecraft.

Method: Several fuel-air mixtures of varying dilution thought to produce stationary spherical flames will be ignited inside the CM-1 combustion chamber. Data on flame luminosity, flame temperature, radiant heat loss, and combustion product composition will be gathered using a variety of cameras and instruments. These data will be examined postmission and compared to computer simulations performed by the Principal Investigator.





This schematic diagram shows what happens in a flame ball in microgravity, while the photograph (left) shows flame balls obtained during the brief period of microgravity available in an aircraft.



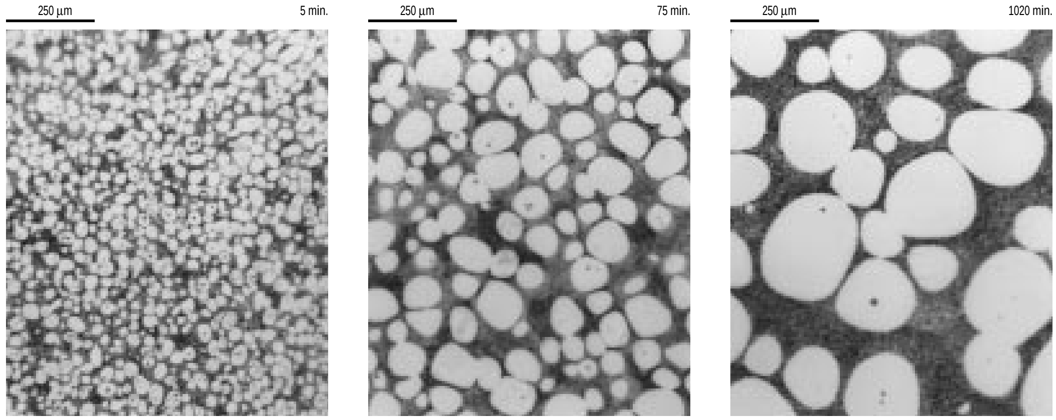
These typical soot aggregates (below) come from diffusion flame environments, such as the weakly buoyant laminar jet diffusion flame (left).

Coarsening in Solid-Liquid Mixtures (CSLM)

Principal Investigator: Dr. Peter Voorhees, Northwestern University

Purpose: to gain an understanding of the coarsening process by direct comparison of the results from this experiment with current theories

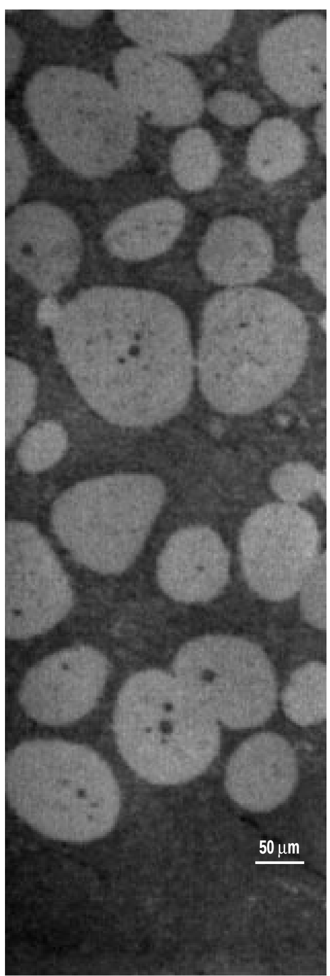
Importance: Coarsening occurs in a variety of materials composed of more than one phase and during many of the processes used to make commercial materials. During coarsening, small particles shrink by loosing atoms to larger particles, causing the larger particles to grow. For example, the second-phase particles in high-temperature turbine blade materials undergo coarsening at the operating temperature of the turbine. This coarsening process degrades the strength of the blade because turbine alloys containing a few large particles are weaker than those containing many small ones. In addition, materials used in nuclear reactors can acquire defects that coarsen and compromise material properties; these defects are radiation induced. Although the driving force for coarsening is well characterized, the speed and mechanisms by which it occurs are not. In applications where human safety depends on material integrity, mechanical failure can have catastrophic results. Coarsening also occurs during sintering, a process used to manufacture items as disparate as dental amalgam for fillings, porcelain, machining tools, and electrical capacitors and plays a major role in determining the properties of the final product. To engineer materials with particular lifetimes and characteristics and to be able to predict those characteristics it is necessary to understand the mechanisms and rates of coarsening.



This sequence of photomicrogaphs shows, from left to right, the process of coarsening in a lead-tin mixture over time. The CSLM experiment will measure the rate at which the average particle size increases with time for various volume fractions of solid.

The solid-liquid lead-tin system in this study allows all of the assumptions implicit in modern theories of coarsening to be realized, with one exception: in microgravity, differences in density between particles and the liquid matrix will not cause particles to float, and the distribution of particles in the matrix should be uniform. Because of the unique environment offered by microgravity, this experiment will be the first to allow direct comparison of experiment data with theoretical models.

Method: The experiment will be performed in an electric furnace in the Middeck Glovebox, located in Spacelab rack 10. The furnace heats the samples held in eight cartridges and melts the matrix surrounding the solid particles. The eight cartridges will be loaded sequentially into the compact oven. Each cartridge is 11.5 cm in diameter and holds 7 samples that are 10 mm in diameter and 5 mm long. Hundreds of thousands of solid particles are dispersed in these small specimens.



On Earth, gravity causes sedimentation of elements with different densities, as seen in this photomicrograph in which the dense lead-rich liquid sample fills the bottom while the less dense tin-rich particles move to the top.

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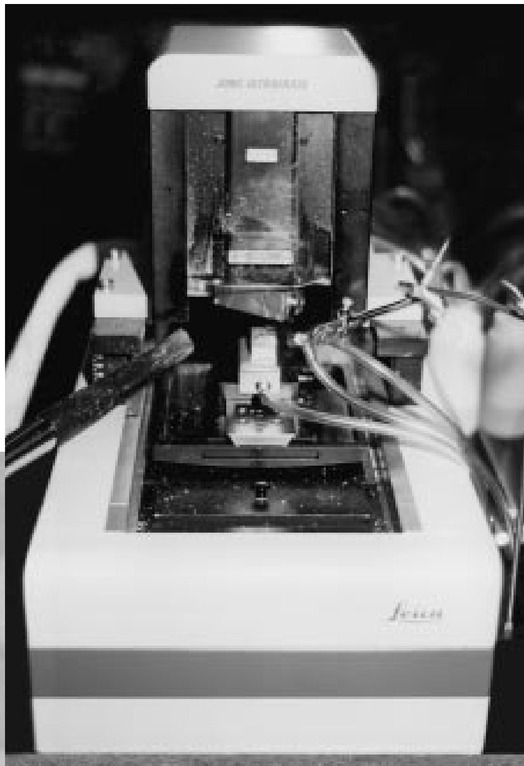
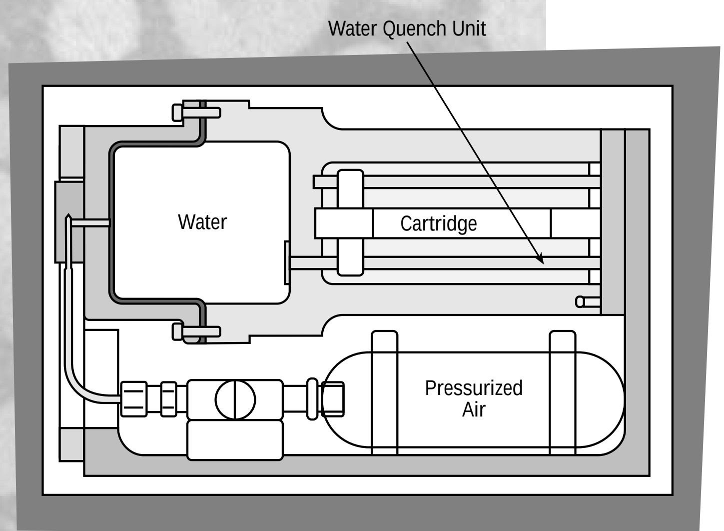


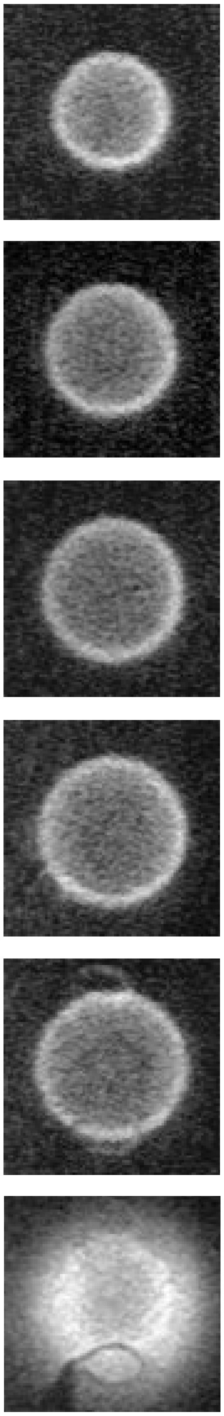
This specially modified microtome will be used to section samples for postmission analysis.

The samples are designed to produce various volume fractions of solid at the coarsening temperature of 185 °C. Each of the specimens in each cartridge will have compositions chosen to yield volume fractions of solid of 0.05, 0.1, 0.2, 0.3, 0.5, 0.7, and 0.8. One cartridge will be processed at each of the following times: 0, 150, 375, 940, 2,340, 5,860, 14,600, and 36,600 seconds. Then, the samples will be quenched rapidly, freezing the high-temperature particle structure. After the mission, quantitative metallographic analysis will be used to determine the coarsening kinetics. The samples will be sectioned, polished, and etched. The images of each section will be digitized for analysis and stored on compact disks for future use. To compare the results to theory, investigators will measure the average radius of the sectioned particles and the particle size distribution as a function of time for each volume fraction of solid.

The rate at which the average section radius changes with time then will be compared with theoretical predictions with no adjustable parameters, the first time this has been possible. To understand the morphology of the solid-liquid mixtures in more detail, scientists will use an electron microscope to analyze the particle contacts that may form during the coarsening. By digitally stacking many two-dimensional images, much in the same way standard medical X-ray tomographic and magnetic resonance images are produced, investigators will be able to reconstruct the full 3-dimensional morphology of the solid-liquid mixtures.



Sample Processing Unit



These ultraviolet images, seen at 0.5-second intervals, show the flame emission of an n-heptane droplet burning in a 30-percent oxygen and 70-percent helium atmosphere.

Droplet Combustion Experiment

Principal Investigator: Dr. Forman Williams, University of California, San Diego

Importance: to test theoretical predictions of liquid-phase steady and unsteady phenomena and extinction phenomena in the spherically symmetrical burning of a pure fuel droplet by extending the range of effective characteristic times over which chemical-kinetic and transport influences can be determined experimentally

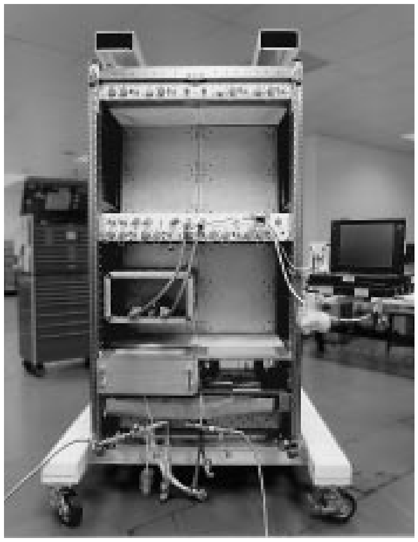
Importance: The combustion of fuel droplets is an important part of many operations, such as the heating of furnaces for materials processing or home heating, power production by gas turbines, and combustion of gasoline in a car's engine. The theoretical predictions behind this process cannot be tested well on Earth because of gravity-induced buoyancy flows. Drop towers and aircraft are unsuitable for this type of experimentation because the time available in towers is too short and aircraft are unable to provide an acceptably low level of microgravity. Experimentation on MSL-1 will permit large droplets to be observed over long periods of time, allowing investigators to gather data for comparison with theoretical predictions of burning rates, flame structures, and extinction conditions. The consequent improved fundamental understanding of droplet combustion may contribute to the clean and safe utilization of fossil fuels.

Method: The Droplet Combustion Apparatus is an enclosed chamber into which controlled helium-oxygen atmospheres are injected and in which single heptane droplets are burned. The initial droplet diameters range from 1 mm to 5 mm. A droplet will be formed by injecting the fuel through two opposed injectors. The injectors then will be retracted slightly to stabilize the droplet and rapidly removed to deploy the droplet in the field of view of the optical measurement apparatus. Two hot-wire igniters will be brought near the droplet from opposite sides to ignite the flame while providing minimum disturbance to the droplet. After ignition, the igniters will be retracted, and the droplet and its flame will be observed as combustion occurs in the selected atmosphere, away from disturbing influences of walls. Besides recording of temperatures and pressures, there will be backlit droplet views, ultraviolet flame views, camcorder observation, and visual and still-camera photographic observations through different optical ports in the chamber.

A crewmember will deploy a fuel droplet to start the experiment. The experiment run will be controlled by an onboard microprocessor being monitored by the crew and investigators on the ground. Based on results, experiment operations can be modified to enhance the scientific return of the experiment. Data will be collected on film and video by 35-mm motion-picture and UV-intensified CCD cameras and downlinked for both real-time and postmission analysis. Then, the results will be compared with theoretical predictions and will be used to develop complete physical and chemical models of heptane droplet combustion in different atmospheres.

EXPRESS Rack

The EXpedite the PRocessing of Experiments to Space Station (EXPRESS) Rack is a Space Station International Standard Payload Rack (ISPR) being flown on MSL-1 as a precursor payload. The Spacelab program provides the structure and subsystem hardware to accommodate the EXPRESS Rack with interfaces like those on Space Station. The EXPRESS Rack provides standard and simple interfaces to payloads, thereby simplifying the integration process of payloads into the rack. The EXPRESS Rack accommodates payloads compatible with the Space Shuttle middeck, Spacehab, and Standard Interface Rack (SIR) drawers, developed by NASA's Life Sciences division. Eight single middeck lockers and two SIR drawers are provided by the EXPRESS Rack for payload use. The Physics of Hard Spheres Experiment (PHaSE) will be housed in four of the middeck lockers and one of the SIR drawers, demonstrating the accommodations for modular, as well as small, payloads. A double-locker payload, the Astro/Plant Generic Bioprocessing Apparatus (PGBA), will be located in the orbiter middeck for launch and relocated to the EXPRESS Rack for operations once on orbit, just as late access payloads will be during the Space Station era.

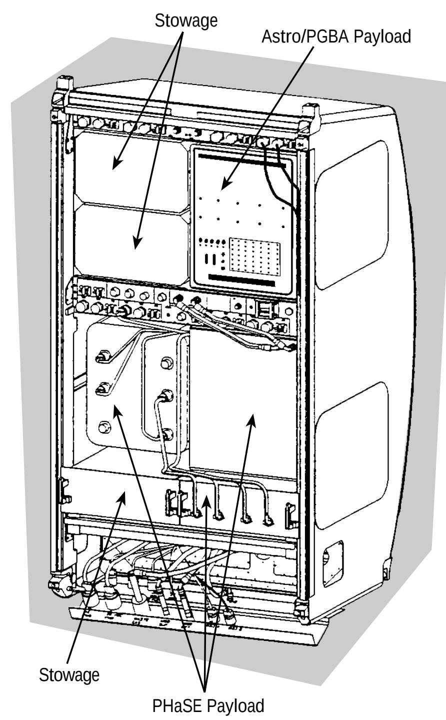


EXPRESS Rack in development for MSL-1

The flight of the EXPRESS Rack on MSL-1 provides an opportunity to test and demonstrate this Space Station hardware. The rack provides for resource distribution to and command and control of the payloads installed in it. It utilizes a Space Station program-provided ISPR, Avionics Air Assembly (AAA), and coldplates. The primary subsystems for the EXPRESS Rack are the AAA, the Solid State Power Controller Module (SSPCM), and the Rack Interface Controller (RIC). The AAA will provide avionics air cooling for payloads on Space Station. Payload exhaust heat will be drawn to the rear of the rack and passed across an air-to-water heat exchanger. The heat then will be transferred to the Spacelab Mission Peculiar Equipment water loop, and the conditioned air will be returned to the Spacelab cabin. The SSPCM provides power distribution and protection to subsystems and payloads in the rack. The RIC provides the communication link between payloads and the Spacelab data system and ground controllers, mimicking the command and control link for the International Space Station. The RIC communicates with payloads via standard data protocols (RS232, RS422) and with the Space Shuttle-provided laptop via ethernet. The RIC will route the payload data in packets, with headers to identify the payload, and will transmit them through the Spacelab data system just as it will with the Space Station data system. The subsystems are coldplate cooled to preserve air cooling for payloads in the rack. Payload power and data connections for the SIR drawers are on the rear of each drawer so that when one is inserted into the rack the connectors will engage. Payload power, data, and water loop connections for the middeck locker payloads are made on their front faces by jumper cables that connect to the appropriate utilities on the EXPRESS Rack connector panels at either the top or mid-section of the rack. A Shuttle program-provided laptop computer will be attached to the rack on orbit, allowing crew control of the rack and its payloads. The EXPRESS payloads may be operated from the payload front panels, the rack front control panels, the EXPRESS Rack laptop, the Spacelab crew workstation, or the ground.

To expedite physical integration at Kennedy Space Center, the EXPRESS Rack program has provided the PHaSE experiment with a Suitcase Simulator, as will be provided to Space Station era payloads. The Suitcase Simulator allows the payload developer to check EXPRESS Rack power and data interfaces at the home site during development and reduces the integration time when the payload and rack meet for the first time at the launch site.

The equipment flown on the MSL-1 mission will prove the EXPRESS Rack hardware concept, validate both the physical and analytical integration processes planned for Space Station, and provide the payload community with a link to Space Station.



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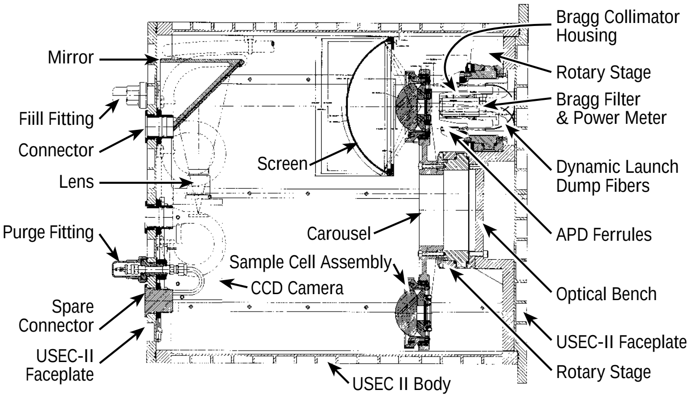
Physics of Hard Spheres Experiment (PHaSE)

Principal Investigator: Dr. Paul Chaikin, Princeton University

Purpose: to help improve the fundamental understanding of the transition from liquid to solid phases through an investigation of the behavior and physical properties of hard spheres

Importance: Of prime importance to many materials processing techniques is an understanding of the fundamental physics of the liquid-to-solid phase transition (and vice versa). This transition can be studied by employing a colloidal system of micron-sized hard spheres tailored to be impenetrable. At specific volume fractions, tailored hard-sphere colloids have demonstrated the behavior of crystal nucleation and growth, driven purely by configurational entropy because of constraints on the packing of the impenetrable particles at high densities.

Method: The experiment will be performed in a multi-angle Light Scattering Instrument (LSI). Within the LSI, seven hard-sphere samples of varying concentrations of three components will be housed in individual glass cells mounted onto a precision rotary stage. The exact ratio of the three components is dependent on the specific volume fraction of solids to liquids desired; each sample will have a slightly different ratio. During operation, each of the samples will be rotated into position for light scattering/data collection activities using both static and dynamic laser sources. Data will be collected using both a high-definition CCD camera to record images of the cells and photon counters to measure light scattering.



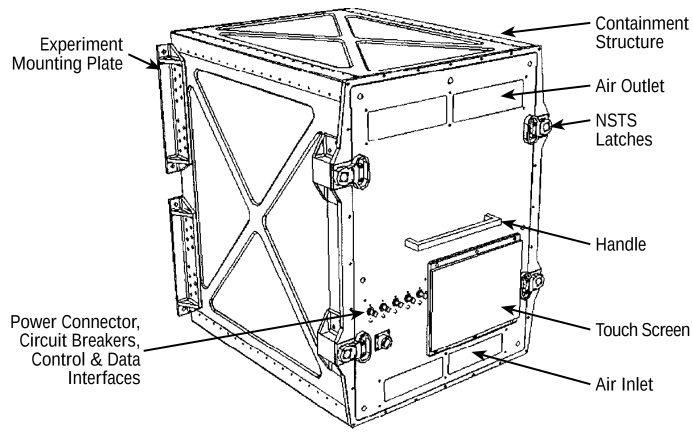
PHaSE

Astro/Plant Generic Bioprocessing Apparatus (Astro/PGBA)

Principal Investigator: Dr. Louis Stodieck, University of Colorado, Boulder

Purpose: to support commercial research and development on adaptation mechanisms of higher plant systems to spaceflight, especially focusing on production of lignin-based structural elements, production of secondary metabolites used as pharmaceuticals, and alterations in sugars and starches in vegetable plants

Importance: Photosynthesis and the production of sugars, starches, amino acids, and proteins by plants serve at least three purposes necessary for a plant's survival: to produce cells and tissues with specialized functions; to produce lignin and other structural elements for support; and to produce various secondary metabolites that may serve a variety of needs, attracting, repelling, or poisoning insects, for instance. Evidence suggests that these processes may be interrelated. In particular, if a plant develops in a microgravity environment, it may be that less metabolic energy would be directed toward lignin production, permitting greater production of secondary metabolites. By studying how plants adapt to spaceflight, it may be possible to learn how to manipulate the same species on Earth to derive significant commercial benefits.



Astro/PGBA

Method: The Astro/PGBA experiment hardware is contained in a double locker that will be installed into the EXPRESS Rack after the Shuttle is in orbit. The hardware consists of a plant growth chamber with a 10-inch by 12-inch growth area that allows 10 inches of plant height and 2 inches of roots. Fluorescent or LEO lighting will simulate sunlight, and an atmospheric control system will maintain set levels of carbon dioxide and humidity while scrubbing volatile organic compounds, such as ethylene, that can accumulate and inhibit plant growth. Plant transpiration water, collected from a dehumidifier system, can be recirculated back into the root matrix. A computer system will control experiment operations and provide engineering and video data for downlink to investigators on the ground.

Several weeks before launch, seeds or cloned cuttings of the plants to be studied will be established in conditions matching those of flight. The plants will be staged at different points in their development to optimize the particular properties being evaluated. The plants to be studied include *Artemisia annua*, a species of sage native to Southeast Asia that is a source of the antimalarial drug artemisinin; *Catharanthus roseus*, which produces vinca alkaloids that are used in the chemotherapeutic treatment of cancer; *Pinus taeda* (loblolly pine), which is used widely in the paper and lumber industries; and *Spinacia oleracea*, a fast growing variety of spinach. Approximately 1 week before launch, the plants will be loaded into the growth chamber and established on the day/night cycle to be used on the mission.

After the mission, the plants will be photographed to record plant size and shape, as well as leaf and root system size and shape, before being dissected and preserved. Frozen samples of leaf, stem, and root materials will be shipped to industry investigators for detailed analysis of lignin and secondary metabolite composition. The data gathered from these and other investigations will be compared with data from plants grown on the ground under near-identical conditions.

Large Isothermal Furnace

The LIF, seen here in front of Dr. Chiao during the IML-2 mission, will be making its third flight on MSL-1.

The Large Isothermal Furnace (LIF) is a vacuum-heating furnace designed to heat large samples uniformly. First used by three investigations on the Spacelab J mission, the LIF has a maximum temperature of 1,600 °C and can cool a sample rapidly through the use of a helium purge. For MSL-1, the furnace has been modified to allow ground commanding of the heating and cooling processes so that investigators can make real-time changes to enhance science operations.

The furnace consists of a sample container and heating element, surrounded by a vacuum chamber. A crewmember will insert a sample cartridge into the furnace, locking it in place. The furnace will be activated, and operations will be controlled automatically by a computer in response to an experiment number entered on the control panel. At the end of operations, helium will be discharged into the furnace, allowing cooling to start.

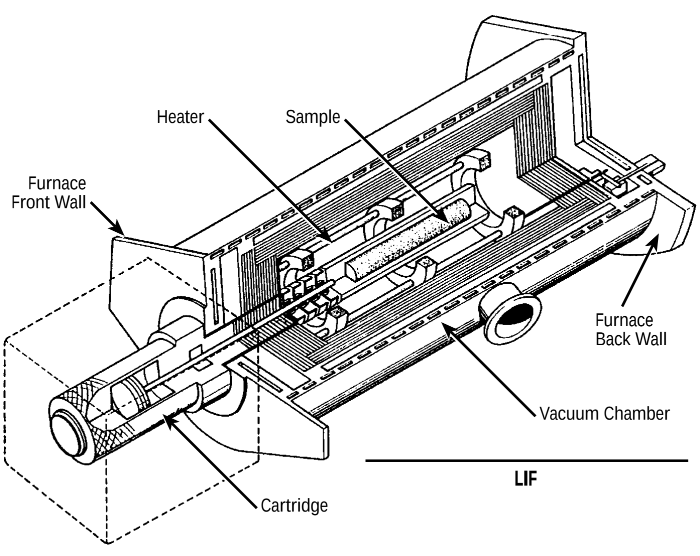
Cooling will occur through the use of a water jacket, while rapid cooling of samples can be accomplished through a controlled flow of helium.

On Earth, two or more components in a liquid state will mix together gradually without outside intervention as a result of convective flows and diffusion — the movement of material in response to differences in concentration or temperature. On Earth, it is not possible to study diffusion flows because the effects of convection and, in small tubes where convection can be reduced or controlled, flow effects — such as capillary action — caused by the wall of the container cannot be quantified or eliminated. In microgravity, convection is reduced or eliminated, allowing the diffusion process to be studied. Data from experiments on diffusion will help scientists better understand this important process, which is vital to the production of high-quality semiconductor crystals.

Two of the five LIF experiments that study diffusion will use the Shear Cell Method, which involves two sample columns with different concentrations of materials. The two columns will be melted, then rotated into contact with each other for a predetermined amount of time. The single column will be sheared into segments and allowed to cool. One experiment will make use of the Middeck Glovebox to take preliminary resistance measurements of its shear cell samples, so that the processing of the next sample can be modified based on these results.

One LIF experiment examines sintering, a process by which particles are joined to form a material using heat and pressure, without reaching the melting point of one or both materials. The growth of solid particles when one of the components is melted is of interest to scientists but cannot be studied effectively on Earth because gravity segregates the solid particles. This segregation affects metallic alloys, reducing desirable traits such as strength and corrosion resistance. In microgravity, segregation is reduced or eliminated, allowing investigators to gather data that will improve current knowledge of this important process.

The knowledge gained from operating the LIF on Spacelab J, IML-2, and MSL-1 is doing more than simply improving knowledge of materials and materials processing in microgravity. Experience in operating the furnace is helping with efforts to create an advanced version for use on the Space Station. This version will be able to heat samples to 2,000 °C and may include other advances in hardware and controls.



LIF

Measurement of Diffusion Coefficient by Shear Cell Method

Principal Investigator:
Dr. Shinichi Yoda, National Space Development Agency of Japan (NASDA)

Purpose: to verify the design and operation of the shear cell cartridge for use in the LIF in microgravity; to obtain accurate measurements of the diffusion coefficient of tin and of lead-tin-telluride

Importance: The shear cell method is an important tool in determining the rate of diffusion in a variety of materials. The ability to conduct experiments in microgravity using this method will open new avenues of investigation.

Method: Samples of tin will be processed at 1,527 °C for 138 minutes, and samples of lead-tin-telluride will be processed at 1,300 °C for 70 minutes. These samples will be examined postmission using Secondary Ion Mass Spectroscopy, Inductively Coupled Plasma Atomic Emission Spectroscopy, and an Electron Probe Microanalyzer to determine the amount of diffusion that occurred during processing. Data from the samples will help clarify the diffusion mechanism and the atomic transport mechanism in liquid materials.

Diffusion of Liquid Metals and Alloys

Principal Investigator:
Dr. Toshio Itami, Hokkaido University

Purpose: to clarify the mechanism of self-diffusion of liquid materials by accurately measuring the self-diffusion constant of liquid tin in microgravity

Importance: Self-diffusion in liquid metals is a very important and fundamental phenomenon. Diffusion experiments at a high temperature on the ground, however, have inevitably suffered from gravitational convection. In addition, the mechanism of diffusion in liquids has not been clarified. This

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experiment will provide the accurate diffusion coefficient and its temperature coefficient of liquid tin in the very high temperature range.
Method: Samples of tin will be processed at temperatures ranging from 627 to 1,327 °C at times ranging from 38 to 227 minutes. These samples will be examined postmission using Secondary Ion Mass Spectroscopy to determine the diffusion coefficient. Data from these samples will help to clarify the diffusion mechanism and the atomic transport mechanism in liquid materials, based on the hard-sphere model and other kinetics theories of liquids. This, in turn, will help in the design of metallic alloys and processing techniques.

Diffusion in Liquid Lead-Tin-Telluride

Principal Investigator: Ms. Misako Uchida, Ishikawajima-Harima Heavy Industries

Purpose: to measure precisely the liquid diffusion coefficient of lead-tin-telluride; to determine its temperature dependence
Importance: Lead-tin-telluride is a potential material for infrared detectors and lasers. It is difficult, however, to make the crystals with a uniform distribution of the component elements since the process is controlled essentially by solutal diffusion at the solid-liquid interface during solidification. The "true" diffusion coefficient in liquid is yet to be obtained because gravity induces buoyancy-driven convection flows that mask this phenomenon. In addition, it appears that the temperature dependence of the diffusion coefficient is different in microgravity.
Method: Samples will be processed at 950 to 1,300 °C for 70 to 100 minutes. The samples will be analyzed postmission with an Electron Probe Microanalyzer to determine the diffusion coefficient. The data from this experiment will be used to determine the best crystal growth parameters for microgravity and to aid in improving analytical models.

Impurity Diffusion in Ionic Melts

Principal Investigator: Dr. Tsutomu Yamamura, Tohoku University

Purpose: to determine accurately the tracer (impurity) diffusion coefficient in molten salts in the absence of gravity-induced convective flows; to evaluate these data in comparison with values determined under normal gravity; to use the results to improve theory
Importance: Precise data on the diffusion coefficients of high-temperature melts is indispensable for the analysis of high-temperature processes, such as crystal growth in melts, and for improving theoretical models. Ground-based experiments, however, have produced an enormous range of values because of disturbances caused by gravity-induced convection.
Method: The samples of potassium chloride, lithium chloride, and silver chloride are contained in closed cylinders designed to minimize the free surface and, thus, minimize surface-tension-driven convection flows and to ensure that the samples are not exposed to outside contaminants. These cylinders also contain an electrochemical cell and circuits to control the current and record data at high speed. These data will be downlinked during the mission in real time, allowing researchers to modify experiment procedures and maximize the scientific return. Initially, the samples will be processed at 360 to 620 °C, 4 to 150 mA/cm^2, for 19 to 147 minutes. Chronopotentiometry data, obtained through testing of the samples, will allow investigators to determine the diffusion coefficient. This information will be used to clarify the tracer diffusion mechanism and elucidate the factors controlling diffusion in molten salts. These precisely determined data then can be used as standards for basic science and engineering work and to determine the optimum conditions for the electrolysis of molten salts.

Liquid Phase Sintering II

Principal Investigator: Dr. Randall German, The Pennsylvania State University

Purpose: to test theories regarding liquid-phase sintering; to examine coalescence during liquid-phase sintering in the microgravity environment; to examine pore behavior
Importance: Sintering is an important industrial process. On Earth, however, gravity limits its use by causing distortion and slumping, solid-liquid separation, and grain coalescence. Experiments have shown that compounds that cannot be sintered on Earth can be sintered in microgravity. They also have shown differences in pore behavior, grain growth kinetics, and grain agglomeration from Earth-based experiments.
Method: Five cartridges will be processed. Each cartridge will contain seven samples with different matrix compositions. One cartridge will be processed for 1 minute, one for 120 minutes, one for 45 minutes, one for 480 minutes, and one for 600 minutes at 1,500 °C. The samples will be examined postmission for dimensional change, solid volume fraction, grain size, connectivity, and contiguity. These data will be compared with theoretical predictions to develop a better understanding of sintering in microgravity and to improve theoretical models.

Diffusion Processes in Molten Semiconductors

Principal Investigator: Dr. David H. Matthiesen, Case Western Reserve University

Purpose: to provide a definitive measurement of the diffusion coefficient; to investigate its dependence on temperature, impurity type, and sample diameter by measuring the diffusion coefficients of trace impurities such as gallium, silicon, and antimony in molten germanium; to use these data to develop models of diffusion
Importance: The movement of trace materials during the processing of semiconductors and other materials results from both diffusive and convective mixing processes. Since current models cannot separate the two processes accurately, scientists cannot quantify the diffusive contribution in Earth-based measurements. This experiment will measure accurately the diffusion of dopants (deliberately added impurities) into germanium.
Method: Six cartridges, each containing a shear cell, will be processed. Each shear cell has two sides, one side with six columns of different diameters, two each for gallium-, silicon-, and antimony-doped germanium samples, and the other with a complementary set of pure germanium. After insertion into the LIF, the cartridge will be heated and the samples stabilized at the furnace temperature. The shear cell's six columns then will be rotated into contact with their pure germanium counterparts, and diffusion will begin. After shearing, solidification, and cooling, the individual segments will be tested for electrical resistance in the Middeck Glovebox, with the data used to modify the processing of the next cartridge. Postmission analysis using Inductively Coupled Plasma Atomic Emission Spectroscopy techniques will provide accurate measurements of the concentration of the dopants and, thus, the diffusion coefficients for each doping.

Measuring Microgravity

Scientists who experiment in a microgravity environment want as few disturbances as possible. Although the effects of Earth's gravity are reduced significantly in the orbiting Shuttle and Spacelab, still there are forces at work that mimic gravity's effects. Even if the orbiter were an empty box with no engines and no experiment or crew activities, certain gravitational and vibrational forces would be present. For example, if this theoretical empty box were orbiting Earth in the very thin atmosphere through which the Shuttle flies, it still would encounter molecules of air that would provide resistance to its movement. This resistance, known as drag, has a very slight slowing effect on the orbiter. Since the density of the atmosphere varies from night to day, the amount of deceleration also varies proportionally.

The location of an experiment in the Shuttle can affect the amount of vibrational disturbance it will experience. Regardless of the attitude of the Shuttle as it orbits Earth, there is an imaginary point that marks its center of gravity. The closer an experiment is located to the center of gravity of the Shuttle, the less it is affected by vibrations or acceleration forces.

In addition to these minimal effects, the Spacelab environment is subject to significant vibrational forces caused by orbiter operations and subsystems and even by the mechanical operations of the experiments. Also, the crew create movements in the Shuttle as they exercise, perform experiments, and tend to housekeeping duties. Thruster firings change or maintain the orbiter attitude and may occur thousands of times during a mission. The amount of disturbance generated by the thruster firings varies according to the combination of jets fired, the pulse strengths, and the duration of the firings. The Ku-band antenna, which transmits data and communications from the orbiter to the Tracking and Data Relay Satellite System, moves continually during the Shuttle mission, changing its alignment to maintain contact with the appropriate satellite. To prevent a condition called "stiction," where mechanical components stick slightly and then release with a slight jerk, the antenna quivers at a frequency of 17 Hz, providing a noticeable vibration. Other orbiter systems produce vibrations with the operation of Freon pumps, air fans, and coolant loops. Some of these vibrations are constant and expected, allowing investigators to plan very sensitive experiments around quieter periods, while other vibrations are more erratic and may have a negative effect on experiments.

The best way to maintain a stable orbital attitude is to keep the tail of the Shuttle pointed toward Earth. In this orientation, the gravity-gradient attitude, the vehicle's position is maintained primarily by natural forces, reducing the number of thruster firings that disturb acceleration-sensitive instruments.

The activities of crewmembers at work inside Spacelab cause vibrations that may disturb sensitive experiments.

Even in a gravity-gradient attitude, unavoidable vibrations can disrupt the quiescent low-gravity environment and may affect microgravity science experiments. Accelerations at particular frequencies may interrupt one type of experiment but have no effect on others. These accelerations are measured at fractions of Earth's gravity; for instance, 10^{-5} is equal to 1/100,000 of the gravity on Earth. If investigators are to draw accurate conclusions from their experiments and to develop future experiments and facilities for microgravity science study, it is crucial that they understand the cause-and-effect relationships between low-level, on-orbit accelerations and the operation of their experiments. Consequently, a group of instruments called accelerometers has been developed to monitor and map the acceleration environment. These systems collect data about small disturbances to the microgravity environment, providing investigators with insight into conditions that might affect the results of their experiments. The MSL payload will include the Space Acceleration Measurement System (SAMS), the Microgravity Measurement Assembly (MMA), the Quasi-Steady Acceleration Measurement (QSAM) system, and the Orbital Acceleration Research Experiment (OARE). OARE will be located outside the Spacelab in the orbiter's payload bay, while the SAMS, MMA, and QSAM instruments will have remote sensor heads located in Spacelab racks 3, 8, 9, 10, and 12 for detection of accelerations affecting the microgravity science experiments housed in those and adjacent hardware racks. Once activated, each of these accelerometers will monitor the Spacelab environment continuously, providing real-time and postflight data to the investigators and hardware developers. After the flight, the microgravity acceleration data from each instrument will be analyzed, and a report will be prepared by the Principal Investigator Microgravity Services (PIMS) project, which will summarize the MSL microgravity environment. The report will help the Principal Investigators analyze science data gathered during the mission.

All four systems are proven spaceflight veterans, affording investigators the opportunity to analyze the microgravity environment in the Space Shuttle over the course of several missions. This information also has helped hardware developers to refine their instruments, isolating the experiments as much as possible from minor disturbances aboard the Space Shuttle.

Space Acceleration Measurement System

Project Scientist: Dr. Peter Tschen, NASA Lewis Research Center

Method: The SAMS instrument has three remote tri-axial sensor heads. Each sensor head has three accelerometers that are oriented at right angles to each other, allowing each sensor head to detect 3-dimensional accelerations in the 0.01- to 100-Hz range. For this mission only, one SAMS sensor head will detect accelerations up to 2.5 Hz, while the others will detect accelerations up to 25 Hz. The

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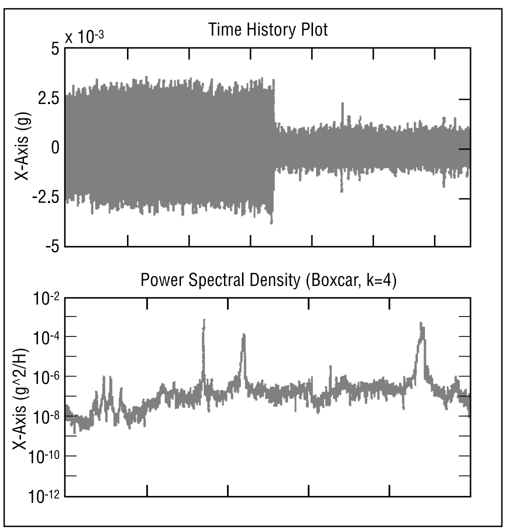
sensors will be connected by cables to a data storage unit in the Spacelab center aisle and will be located on or near the Combustion Module, the Large Isothermal Furnace, and the Glovebox in Spacelab racks 8, 9, and 12, respectively. The main unit to which each of these is connected will be in the Spacelab center aisle between racks 3 and 4.

Each accelerometer consists of a mass suspended by a quartz element so that movement is allowed along one axis only. A coil is attached to the mass, and the assembly is placed in a magnetic field. An applied acceleration moves the mass from its rest position, altering the magnetic field and causing current to flow in an electrical circuit. The current is proportional to the force of the acceleration.



SAMS Data Plot. These plots of SAMS data from the Spacelab J mission show examples of typical vibrations produced by equipment operations on Spacelab J. The abrupt drop in acceleration approximately 70 seconds into the time history plot indicates a decrease in vibrational level when the Life Sciences Laboratory Equipment (LSLE) refrigerator/freezer compressor cycled off. In the corresponding power spectral density plot, the peaks at about 22 and 44 Hz represent the frequencies excited by the LSLE. The sharp linear peak at 17 Hz is related to the dither of the Ku-band antenna. Lower peaks below 10 Hz are associated with orbiter structural frequencies.

The instrument's electronics convert the current into voltage and then into digital data for processing by its computer. These data will be transmitted to scientists on the ground for near real-time processing and science support and also will be recorded for postflight analysis. In addition to providing support for experiment operations occurring in real time, this information will assist experiment developers in preparing for future flights.

Microgravity Measurement Assembly

Project Scientist:
Dr. Hans Hamacher, DLR

Method: The MMA is a microgravity monitoring system capable of providing real-time display of accelerations detected by seven sensor heads that measure accelerations in three axes. Four of these sensor heads will be deployed in Spacelab racks, where many gravity-sensitive investigations are located. Most of the MMA sensors can detect accelerations in the 0.1- to 100-Hz range. One sensor, called the Accéléromètre Spatial Triaxial Electrostatique (ASTRE) measures accelerations below 1.0 Hz. The ASTRE working principle is based on keeping a proof-mass motionless in a fixed position and attitude by electrostatic suspension. By measuring the strength of the electrostatic force that is required to keep the proof-mass stationary, scientists can measure the acceleration levels in three dimensions.

The analog data from the sensors are routed to the instrument's central Microgravity Measurement Electronics computer for processing, formatting, and downloading. The real-time analysis of the data will enable scientists on the ground to have an immediate assessment of the microgravity environment and to plan for possible corrective actions for their experiments.

Quasi-Steady Acceleration Measurement

Project Scientist:
Dr. Hans Hamacher, DLR

Method: The QSAM system is primarily designed to detect steady, very low-frequency, residual accelerations between 0 and 0.02 Hz. In this range, the acceleration level is typically 10^{-6} or even lower, and these low-frequency accelerations affect various physical processes more than higher frequency accelerations. Unlike other measurement systems, QSAM suppresses the sensor's bias and noise to assess this acceleration range with a minimum of on-orbit maintenance. To achieve this, the measurement signal can be modulated by rotating a sensor's sensitive axis. The system employs four rotating sensors to allow 3-dimensional acceleration detection. An additional package with stationary sensors has an upper bandwidth of 50 Hz. For the MSL-1 mission, the QSAM system will be located in the lower left side of Spacelab double rack 3; however, data can be modeled to calculate the low-frequency accelerations at other locations inside the orbiter. These measurements of quasi-steady accelerations will continue to build the database characterizing the microgravity environment aboard Spacelab. QSAM complements the other systems measuring disturbances on this mission, providing detection of the entire range of accelerations that may affect experiments.

Orbital Acceleration Research Experiment

Project Scientist: Dr. Peter Tschen, NASA Lewis Research Center

Method: The OARE is a self-calibrating instrument designed to measure very low-frequency microgravity acceleration signals on the Space Shuttle with very high resolution. The OARE measures accelerations caused by upper atmospheric drag, rigid body inertial rotations, gravity-gradient effects, Shuttle mass expulsion, and crew activities with an accuracy of less than 10^{-8} times Earth's gravity and in a frequency range less than 0.1 Hz. Measurement of these very low-level forces during on-orbit operations is possible because of the Miniature ElectroStatic Accelerometer (MESA) cylindrical sensor device contained within the OARE package.

The OARE has a cylindrical mass (a proof-mass) suspended within an electrostatic field in the accelerometer housing. The proof-mass is pulled in different directions by static electric fields generated by electrodes within the housing. When the fields exert equal pulls in all directions on the proof-mass, it floats between them. This is known as electrostatic suspension. An acceleration in any direction will cause the proof-mass to move with respect to its enclosure, distorting the suspending electrostatic field. These field distortions are proportional to the applied acceleration and are measured and interpreted by the instrument's electronics. Computer software will condition the acceleration data by removing frequencies above this level and will downlink the data to scientists monitoring their experiments from the ground.

MIDDECK GLOVEBOX

The Middeck Glovebox (MGBX), developed by Marshall Space Flight Center, offers scientists the capability to conduct experiments, test science procedures, and develop new technologies in microgravity. It enables crewmembers to handle, transfer, and manipulate experiment hardware and materials that are not approved for use in the open Spacelab. In addition, the facility is equipped with photographic equipment and video and data recording capability, allowing a complete record of experiment operations.

The original Spacelab Glovebox, provided by the European Space Agency, was part of the payload on the First and Second United States Microgravity Laboratory missions. In 1995, based on lessons learned, engineers at Marshall Space Flight Center developed a new facility, equipped with a video recording system that can provide three simultaneous views of Glovebox investigations and records five channels of both digital and analog data. Also, the new facility has a larger working area and improved lighting and supplies more status information on environmental factors such as humidity. With scheduled flights on MSL-1, USMP-4, and MIR, the Middeck Glovebox is proving to be an effective bridge between the earlier facility and the Microgravity Science Glovebox planned for Space Station.

The Middeck Glovebox consists of an Interface Frame (IF) and Glovebox (GBX). The facility was developed for use in the middeck but will be mounted in Spacelab rack 12 for the MSL-1 mission. The IF furnishes structural, thermal, and electrical interfaces to the orbiter and to the Glovebox, as well as operational capabilities for the data and video recording equipment. The Glovebox provides a sealed work area that presents a clean working space and minimizes contamination risks, both to Spacelab and to experiment samples. It provides two types of containment: physical isolation and a negative air pressure differential between the enclosure and the rest of the Spacelab working area. The facility has a filter system designed to contain fluids, powders, and other solid particles, preventing them from entering the Spacelab environment. Also, the Glovebox protects samples from contamination from external sources when experiment procedures call for containers to be opened.

Microgravity experiments benefit from the following MGBX features: a large viewing window atop the cabinet, equipment to mount and position experiments, real-time downlink of experiment video and housekeeping data, electrical power, partial temperature control, time-temperature display, and adjustable lighting. It has one black-and-white and two color video channels to record experiment operations and specimen behavior, a back-light panel, a 35-mm camera, and a microscope that offers high-magnification viewing and the capability to record images when used in concert with the video or still cameras.

The crew will manipulate samples or experiment equipment through three doors: two glovedoors and a central port through which experiments are placed in the Glovebox. The glovedoors are located on each side of the central port and serve three functions. When an airtight seal is required, crewmembers can insert their hands into rugged gloves attached to the glovedoors, allowing no airflow between the enclosure and Spacelab. If the experiment requires more sensitive handling, crewmembers may put on surgical gloves and insert their arms through a set of adjustable sleeves. In addition, each of the doors serves as a viewport for the facility's video cameras.

General operations require the crew to unstow experiment modules and specimens and move them into the Glovebox enclosure. Most of the experiment modules in the Glovebox have magnetic bases or strips that hold them to the metal floor of the enclosure, or they can be mounted to attachment points on the floor. Others attach to a laboratory jack in the enclosure, which can position the module at a chosen height above the cabinet floor. Experiment equipment also may be bolted to the left wall of the working space.

Once the experiment equipment is secured, the crew will proceed with operations specific to a particular investigation. Following the experiment, the crew will clean up any spills or leaks in the workspace, reassemble the hardware if necessary, and move it back into stowage.

For the MSL-1 mission, the Middeck Glovebox experiments fall into two basic categories: fluids and combustion. The four experiments test or demonstrate microgravity science theories, procedures, and hardware.

Bubble and Drop Nonlinear Dynamics (BDND)

Principal Investigator: Dr. L.G. Leal, University of California at Santa Barbara

Purpose: to measure nonlinear oscillation characteristics of bubbles when the dominating force is provided by surface tension; to assess the capability of ultrasonic radiation pressure for the manipulation of bubbles

Importance: By understanding how the shape and behavior of bubbles change in response to ultrasonic radiation pressure, it may be possible to develop techniques that eliminate or counteract the complications that bubbles cause during materials processing. The large amplitude deformation and oscillations of bubbles and drops are of fundamental scientific interest because of their inherent nonlinear characteristics. For example, although the resonant frequency for shape oscillations changes with the amplitude of the oscillations and also with the static shape distortion, the size of the frequency change is not directly proportional to either; the effects are non-additive. Also, many industrial applications, including the solidification of certain alloys, involve multiphase systems where large number dispersions of bubbles and drops are used. Examples of multiphase systems include bubbles of a gas-phase material dispersed in a matrix of liquid-phase material and immiscible systems.

Method: To measure nonlinear oscillation characteristics of bubbles in response to surface tension forces, single air bubbles will be deployed in a water-filled ultrasonic resonant chamber where they will be positioned actively. Using radiation pressure, their shape will be deformed, and their oscillatory response to this deformation will be recorded through an optical detection method. Specifically, scientists will assess their ability to control bubble location, manipulate double bubbles, and maximize bubble shape. Shape deformation will be studied as a function of size and ultrasonic pressure. The effect of ultrasonic radiation pressure on bubbles also will be assessed through the study of the coalescence of two single bubbles. Investigators will measure coalescence time as a function of the ultrasonic pressure in pure water and in the presence of a known surfactant contaminate.

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A Study of the Fundamental Operation of a Capillary-driven Heat Transfer (CHT) Device in Microgravity

Principal Investigator: Dr. Kevin P. Hallinan, University of Dayton

Purpose: to gain an improved physical understanding of the mechanisms leading to the unstable operation and failure of capillary-pumped phase change heat transfer devices in low gravity

Importance: Capillary-pumped loops (CPLs) are devices that transfer heat from one location to another, specifically those that move heat away from one location. In low-gravity applications, such as satellites, CPLs are used to transfer heat from electrical devices to space radiators. The transfer of heat is accomplished by evaporating from one liquid surface at the hot side and condensing the vapor produced at another liquid surface at the cold side. Capillary action is used to “pump” the liquid back to the evaporating liquid surface (hot side) to complete the “loop.” The function of this closed loop is to transport the heat present in the vapor produced by evaporation at the hot side to the cold side where it is discharged by radiation to the surrounding area.

CPLs require no power to operate, and they can transfer heat across distances as large as 30 feet or more. Their reliance upon evaporation and condensation makes them much more economical in terms of weight than conventional heat-transfer systems. CPLs, however, have proven to be unreliable in space operations, and the explanation for this has been elusive. This experiment investigates the fundamental fluid physics phenomena thought to be responsible for the failure of CPLs in low-gravity operations.

Method: The operation of an idealized model of a capillary-pumped loop will be studied. The test cell is a glass loop in a race-track configuration, which will be partially filled with liquid methanol. The condenser side is a tube 10 mm in diameter, and the evaporator side is a tube 1 mm in diameter. A second test cell also will be used; in this cell, the evaporator side will be 4 mm in diameter. The difference in the evaporator diameters will provide a comparison of the loop behavior when the capillary “pumping” is different. (A smaller diameter provides a greater capacity to move the liquid.) During the tests, the evaporator section will be heated independently, both above and below the liquid surface. Temperature and pressure data will be monitored and recorded during the operations. Also, the behavior of the liquid surfaces will be monitored and recorded for further analysis. The data will be used to evaluate conditions and properties that affect the system operations.

Internal Flows in a Free Drop (IFFD)

Principal Investigator: Dr. S.S. Sadhal, University of Southern California

Purpose: to assess the capability of current non-contact and remote manipulation techniques for the control of the position and motion of free liquids in microgravity; to attempt the first measurement of thermocapillary flows in a totally free drop

Importance: Acoustic positioning is an important technique used in containerless processing of materials and in non-contact measurements of the thermophysical properties (viscosity and surface tension) of materials. This investigation will allow the assessment of the potential of acoustic positioning for performing these activities. A successful outcome will impact current understanding of the physics of totally unconstrained liquid-gas interfaces. This information is relevant to many processes in the natural environment and in chemical manufacturing industries, including areas such as petroleum technology, cosmetics, and food sciences.

Method: Free single liquid drops will be deployed and positioned actively by ultrasonic radiation pressure to allow study of their internal flows under isothermal and non-isothermal conditions. Tracer particles within the drops will be visualized, using elastic scattering of laser illumination, and their motion will be recorded by video cameras. Preliminary measurement of thermocapillary flows induced by spot heating of the drop surface will be attempted.

Fiber Supported Droplet Combustion (FSDC)

Principal Investigator: Dr. F.A. Williams, University of California, San Diego

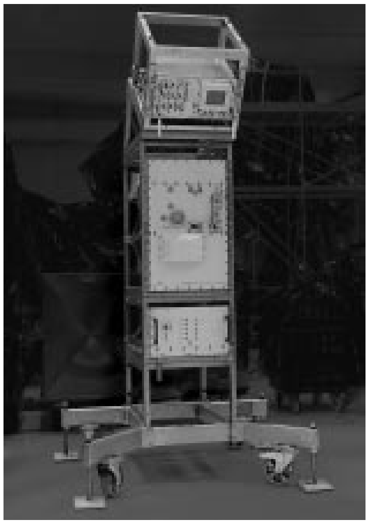
Purpose: to investigate combustion of single large droplets of various fuels in air, using a thin fiber for positioning

Importance: Combustion of large droplets is difficult to study on Earth. Gravity causes the hot combustion products to rise and distorts the flame shape from the spherically symmetric shape observed in low gravity. It also is difficult to control the flow generated by the buoyancy-induced forces without adversely affecting other factors that influence the burning process. The fiber-support technique enables researchers to position the droplet within the view of diagnostic cameras with relative ease and to measure fundamental burning characteristics, such as burning rates, flame positions, and extinction diameters, for a variety of fuels. In addition, the influence of convection on the burning characteristics is measured by imposing a controlled air flow. The understanding gained in these studies is relevant to efficient utilization of fossil fuels and reduction of air pollutants.

Method: Measured amounts of fuel (n-heptane, n-decane, methanol, ethanol, methanol/water mixtures, and heptane/hexadecane mixtures) will be dispensed onto a silicon-carbide fiber to generate droplets that vary between 3 to 6 mm in diameter. Once the fuel is dispensed, the needles will be withdrawn rapidly, leaving the droplet suspended on the fiber. A hot-wire igniter will ignite the fuel vapor. The combustion process will be recorded using three cameras. The first camera provides the backlit view of the droplet from which the burning rate and the extinction diameter of the fuel are obtained. The second color camera provides the flame view, and the third records the radiation levels displayed on LEDs measured by two radiometers.

Electromagnetic Containerless Processing Facility

Tiegelfreies Elektromagnetisches Prozessieren Unter Schwerelosigkeit (TEMPUS)



TEMPUS, an electromagnetic levitation facility that allows containerless processing of metallic samples in microgravity, first flew on the IML-2 Spacelab mission. The principle of electromagnetic levitation is used commonly in ground-based experiments to melt and then cool metallic melts below their freezing points without solidification occurring (undercooling). In terrestrial laboratories, however, strong electromagnetic fields are required to overcome gravitational pull when levitating molten metals and alloys, resulting in the absorption of large amounts of heat by the specimens and requiring that they be cooled convectively by a gas atmosphere. The problem created by this requirement is that samples may be contaminated by impurities from the cooling gas, leading to heterogeneous nucleation. Further complicating the situation is that the turbulent flow generated by the levitating force may cause the melt to nucleate prematurely, masking the true nature of the nucleation kinetics. Because of the presence of the cooling gas, the heat balance of the sample is not known precisely; therefore, scientists cannot measure the specific heat on the levitated specimens. In microgravity, sample positioning and temperature control can be accomplished accurately and precisely because the power necessary for positioning is significantly reduced, also minimizing turbulent fluid flow. Samples can be undercooled and solidified in an ultra-clean, ultra-high vacuum (UHV) or high-purity noble gas atmosphere, guaranteeing a well-defined heat balance and improving the purity of the environment in which the samples are processed.

During the MSL-1 mission, scientists will perform refined IML-2 experiments, studying various thermodynamic and kinetic properties of up to 22 samples. For each investigation, a spherical 7- to 8-mm sample will be positioned by the electromagnetic coil, melted, and then cooled. Melting points of the samples range between 760 and 1,850 °C, with the maximum sample temperature about 2,100 °C.

The TEMPUS operation is controlled by its own microprocessor system, although commands may be sent remotely from the ground, and real-time adjustments may be made by the crew. Two video cameras, a two-color pyrometer and a fast Si-based single color pyrometer for measuring sample temperatures, and a fast infrared detector for monitoring solidification spikes, will be mounted to the process chamber to facilitate observation and analysis. In addition, a dedicated high-resolution video camera can be attached to TEMPUS to measure the sample volume precisely.

The MSL-1 TEMPUS facility has been upgraded with a new levitation coil system to improve positioning stability of the levitated samples. Sample stability can be improved further by automated real-time video analysis, allowing the electronics to recalibrate power to damp excursions actively within the levitation coil. Also, the facility will have a new sample holder to prevent sample contamination and metal vapor deposition on the coils, a residual gas analyzer for *in-situ* monitoring of the processing environment, and improved data-handling techniques for better on-line operation of the experiment process. An electromagnetic levitation facility is being planned for Space Station, and the knowledge provided by these Spacelab operations will allow scientists to improve facility design, refine experiment techniques, and verify initial results.

Experiments on Nucleation in Different Flow Regimes

Principal Investigator: Dr. Robert Bayuzick, Vanderbilt University

Purpose: to determine quantitatively the temperatures of solid nucleations from melts of pure zirconium and the number of nucleations at each temperature as the melts are cooled below their equilibrium freezing points under laminar and turbulent liquid flow conditions

Importance: Current understanding of nucleation of solids from their parent liquids is predicated on the classical nucleation theory, which leads investigators to expect shifts to occur in local arrangements in atoms within a liquid until, eventually, a solid is formed. This idea does not incorporate any effects such as liquid flow or mechanical disturbances, however. A systematic study demands free-floating melts, great control of conditions within the melt, and very careful measurement of temperature, a combination of requirements that is now possible because of the unique conditions provided by Spacelab.

Thermophysical Properties of Undercooled Metallic Melts

Principal Investigator: Dr. Ivan Egry, DLR

Purpose: to measure surface tension, viscosity, and electrical conductivity of liquid and undercooled alloys, specifically palladium-copper-silicon (Pd-Cu-Si) and cobalt-palladium (Co-Pd)

Importance: This experiment will provide information about he thermophysical properties of undercooled metallic melts as a function of temperature and concentration. These data will complement existing information on liquid metals at and above the melting point, providing insight into the largely unexplored metastable state of an undercooled liquid.

Thermophysical Properties of Advanced Materials in the Undercooled Liquid State

Principal Investigator: Prof. Dr. Hans F. Fecht, Technical University Berlin

Purpose: to measure the specific heat of undercooled metallic melts to further current understanding of how metallic glass forms in zirconium-based alloys (ZrNi, ZrAlNiCu, and ZrAlNiCuCo) by cooling of the liquid or by melting of the crystal

Importance: Calculations of thermodynamic functions, such as the Gibbs free energies and entropies of undercooled melts, will allow investigators to draw conclusions about the thermodynamic stability of these metastable systems and to determine the reduced glass transition temperature, an indication of the ability of certain alloys to form glasses. Comparison of different alloy systems should indicate how the glass-forming ability of an alloy is related to its composition. These data can be used to improve design criteria for the formation of bulk metallic glasses and to optimize glass-forming compositions in Earth-based laboratories.

Continued on other side.

Electromagnetic Containerless Processing Facility

Measurements of the Surface Tension of Liquid and Undercooled Metallic Melts by Oscillating Drop Technique

Principal Investigator: Dr. Martin G. Frohberg, Technical University Berlin

Purpose: to investigate the concentration and temperature dependence of the surface tension of liquid with an emphasis on undercooled metallic alloys (pure zirconium, gold, nickel, stainless steel, metallic glasses, and aluminum alloys)

Importance: Sufficient data about the surface tension of liquid metallic alloys do not exist. Investigators need additional information about the interpretation of metal-gas and metal-slag reactions, material flow at a boundary between different liquids, wettability of refractory materials, filtration of melts, sintering of metallic powder, solidification processes, and conditions that would allow optimum weldability and soldering.

Alloy Undercooling Experiments

Principal Investigator: Dr. Merton Flemings, Massachusetts Institute of Technology

Purpose: to measure the solidification velocity in steel alloys, using a combination of video and pyrometric techniques

Importance: This experiment is designed to yield information on phase selection and growth kinetics with limited melt convection. The work has direct application to the design of steel strip casting facilities on Earth and helps scientists understand how welding processes may be conducted in space.

Study of the Morphological Stability of Growing Dendrites by Comparative Dendrite Velocity Measurements on Pure Ni and a Dilute Ni-C Alloy in the Earth and Space Laboratory

Principal Investigator: Dr. D.M. Herlach, DLR

Purpose: to verify theoretical predictions on dendritic growth behavior; to study the influence of melt convection on crystal growth velocities of pure nickel (Ni) and dilute nickel-carbon (Ni-C) alloy melts

Importance: On Earth, convection produces fluid flow velocities in the melt of approximately the same order of magnitude as the dendritic growth, which may conceal this phenomenon; however, in microgravity, convection is reduced, and the validity of the theory can be tested by comparing measurements of the dendrite growth velocity on pure Ni and on a dilute Ni-C alloy containing less than 1% carbon. If the expected influence of melt convection on the dendritic growth velocity at small melt undercoolings can be proven, scientists hope to conduct experiments on other metallic alloys in microgravity. More information about dendrite growth in melts at small undercoolings could have significance in many manufacturing processes, such as welding and casting.

Undercooled Melts of Alloys with Polytetrahedral Short-Range Order

Principal Investigator: Dr. D.M. Herlach, DLR

Purpose: to investigate the maximum undercoolability and the temperature dependence of the specific heat of melts of the quasicrystal-forming alloys $Al_{60}Cu_{34}Fe_6$, $Al_{65}Cu_{25}Co_{10}$, and $Al_{64}Cu_{22}Co_{14}$

Importance: This investigation is intended to deliver improved data on the maximum undercoolability of aluminum-copper-iron and aluminum-copper-cobalt melts. These data are expected to provide a better understanding of nucleation and short-range order phenomena occurring in undercooled melts. Also, the specific heat of the melt, which will be measured as a function of the temperature in the regime of the undercooled melt, is an important parameter for the modeling of nucleation and growth processes; therefore, measurement of the specific heat will improve the analysis of undercooling experiments performed in space, as well as those performed on Earth.

Thermal Expansion of Glass Forming Metallic Alloys in the Undercooled State

Principal Investigator: Prof. Dr. K. Samwer, Institute for Physics, University of Augsburg

Purpose: to investigate the thermal expansion of multicomponent amorphous alloys in a wide temperature range between the melting point and the glass transition temperature of the sample

Importance: This experiment is expected to reveal new information about both a thermodynamic approach to glassy and undercooled metals and the existence of structural changes in the undercooled alloys, which is important for the development of new customized materials. A CCD camera-based optical system (659 x 494 pixels) will image the sample. The edge of the sample will be determined with a subpixel algorithm to achieve an accuracy of 1/10 pixel and will be used to determine the diameter and volume of the sample. This measuring technique can be used with a large class of materials, including metallic glasses, and can be conducted in parallel with and in addition to other TEMPUS experiments.

AC Calorimetry and Thermophysical Properties of Bulk Glass-Forming Metallic Liquids

Principal Investigator: Dr. W.L. Johnson, California Institute of Technology

Purpose: to measure thermophysical properties (specific heat capacity, thermal conductivity, nucleation rates, surface tension, viscosity, and thermal expansion) of good glass-forming metallic alloys to allow improvement of process technologies for such materials.

Importance: The samples processed during the MSL-1 mission will be zirconium-based multicomponent systems similar to Vitreloy™ (Zr-Ni-Cu-Ti-Be) and Zr-Ni-Cu-Ti alloys. These materials are highly processable; they can be cast to net-shape with superior properties, as compared to their crystalline counterparts. Also, they exhibit no solidification shrinkage, require almost no finishing, and have properties equal to or better than the same materials produced by forging.

Measurement of Surface Tension and Viscosity of Undercooled Liquid Metals

Principal Investigators: Dr. Julian Szekely (deceased), Dr. Merton Flemings, and Dr. Gerardo Trapaga, Massachusetts Institute of Technology

Purpose: to demonstrate a containerless technique for measuring the viscosity and surface tension of reactive and undercooled liquid metals, such as zirconium, titanium, and metallic glass-forming alloys

Importance: To measure the viscosity of a liquid, the internal flow velocity must be kept below a certain value to prevent a transition to turbulence. In ground-based electromagnetic levitation, the same forces that levitate the sample against gravity drive intensely turbulent internal fluid flows, making the measurement of viscosity impossible in such ground-based experiments. In microgravity, however, the force and fluid flow velocity is greatly reduced. With care, it is possible to reduce the internal fluid velocity below the transitional velocity to measure the molecular viscosity of the fluid.

PROTEIN CRYSTAL GROWTH

Each cell in living organisms contains thousands of different proteins, which play essential roles in the maintenance of life. Some proteins maintain the structure of the cell; some function as enzymes that initiate or control biochemical reactions; some fight disease; and others send or receive messages between cells. Some proteins even attach to the deoxyribonucleic acid (DNA), which determines individual hereditary characteristics, enabling the transfer of genetic instructions into new proteins. Because the function of a protein is determined by its structure, it is critical that we expand our knowledge about the design of these vital life-sustaining organic compounds.

The structures of many important proteins, however, remain a mystery simply because researchers are unable to obtain crystals of sufficient quality or size. Conditions on Earth limit the size and quality of many protein crystals, but the microgravity environment of space shows promise of allowing the production of larger, more highly ordered crystals by minimizing the effects of sedimentation and convection on crystal growth. For many proteins, this results in more uniform and highly ordered structures with fewer defects than are found in the same proteins crystallized on Earth.

The purpose of NASA's Protein Crystal Growth (PCG) experiments is to produce large, well-ordered crystals of various proteins under controlled conditions in microgravity. Since 1985, NASA has flown multiple PCG experiments on the Space Shuttle, producing large, high-quality crystals of many proteins. These crystals are used in ground-based analyses to determine the 3-dimensional molecular structure of each protein through a process called X-ray diffraction. In this procedure, a crystal is subjected to a beam of X-rays, which are scattered in a regular manner by the atoms in the crystal. The diffracted rays are recorded on an imaging plate, photographic film, or electric counter. Then, computers analyze the intensities of the diffracted rays, providing clues to the molecular structure. Synchrotron accelerators, giant rings that generate bursts of powerful radiation by accelerating electrons to nearly the speed of light, have facilitated the work of crystallographers greatly in recent years. This complex analysis reveals the way the chemical components of proteins are assembled in 3-dimensional space, enabling scientists to discover recurrent structural patterns that perform similar functions or that developed from a common ancestral protein. By identifying these key patterns, they will achieve a better understanding of major cellular processes, such as how cells are able to develop, differentiate, and regulate themselves. This knowledge has potential benefits for many areas of biotechnology, providing information on basic biological processes, allowing the development of food crops with higher nutritional content and increased resistance to disease and supporting basic research toward the development of more effective drugs.

On the MSL-1 mission, three protein crystal growth experiments will be conducted. The Protein Crystallization Apparatus for Microgravity (PCAM) experiment uses trays to grow protein crystals in 378 chambers that are housed in a Single-locker Thermal Enclosure System (STES), which is located in a middeck locker. PCAMs also are stowed in the middeck at ambient temperature. The Second Generation Vapor Diffusion Apparatus (VDA-2) occupies another STES and grows large quantities of crystals in 80 chambers. The third PCG experiment is conducted in four Hand-Held Diffusion Test Cells (HHDTCs), which have eight individual cells each. The PCAMs and VDA-2 experiments use the vapor diffusion process to grow crystals, while the HHDTC investigation uses the liquid-liquid diffusion method. The VDA-2 and HHDTC experiments are recorded on video and/or 35-mm film.

Protein Crystal Growth Using the Protein Crystallization Apparatus for Microgravity (PCAM)

Principal Investigator:
Dr. Daniel Carter,
NASA Marshall Space Flight Center

Purpose: to grow large quantities of various proteins in an STES and in ambient stowage, using the vapor diffusion method

Importance: Precise atomic structure is of fundamental importance in understanding molecular function and can speed development of vaccines, pharmaceuticals, and inhibitory agents to prevent or cure diseases. Also, by growing crystals in a microgravity environment, crystallographers are able to determine factors that exert important influences on the growth of high-quality crystals, including measurements of such crystal properties as resolution, defect structure, and mosaicity.

As a result of space-based research, several crystal structures now have been refined to significantly higher resolution than had been obtained with similar ground-based methods. Recent spaceflights of longer duration, such as the USML-2 mission, have produced additional important successes; for example, Human Antithrombin III crystals produced during the mission were superior to any grown previously, allowing crystallographers to refine the atomic model for the first time.

Method: The most common method of growing protein crystals is a technique called vapor diffusion, which relies on water vapor pressure differences between two solutions within a chamber to create ideal growth conditions. In the chamber, a solution of water and protein is surrounded by a solution that attracts water. The solution is called a precipitant and usually is composed of salts. Differences in vapor pressure between the two solutions cause water to diffuse out of the protein solution and into the surrounding reservoir. As the protein concentrations increase, crystals begin to nucleate and grow.

This experiment relies on six PCAM units. Nine growth trays are located in each PCAM cylinder, and each tray has seven growth chambers. The PCAM units are activated when a member of the Spacelab crew turns a knob that lifts a seal, exposing the protein solutions to the precipitating agents. Once the units are activated, the door of the STES is closed, and crystals are allowed to grow for the remainder of the mission. Reversing the procedure deactivates the experiments to protect the crystals during landing.

Protein Crystal Growth Using the Second Generation Vapor Diffusion Apparatus (VDA-2)

Principal Investigator:
Dr. Larry DeLucas, Center for Macromolecular Crystallography

Purpose: to grow high-quality crystals of various proteins using the vapor diffusion method

Importance: The growth of high-quality crystals has been a major bottleneck in protein crystallography, which, in addition to furthering current basic understanding of biological systems, is critically important in structure-based drug design. Structural information from crystallographic studies of target enzymes is used to design new drugs for the treatment of chronic conditions and diseases. More than 100 different proteins have been

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flown in microgravity crystallization experiments, and approximately 30 percent of these have produced crystals superior to their Earth-grown counterparts. X-ray diffraction data obtained from these crystals has contributed to the determination of the 3-dimensional structures of several proteins and greatly refined the structural information for many others. Among the proteins that have produced superior crystals in microgravity are isocitrate lyase, canavalin, satellite mosaic virus, human serum albumin, Factor D, human aldehyde reductase, epidermal growth factor receptor, and human insulin.

Method: The VDA-2 hardware consists of 4 trays, each containing 20 crystallization chambers. Before launch, protein and precipitant solutions are loaded into the two larger barrels of triple-barreled syringes. The third barrel has a smaller diameter and is used only for mixing. Each syringe is capped and installed into a crystallization chamber. More concentrated precipitating agent solution is injected into the polymer wicking material that lines the crystallization chambers. The VDA-2 trays are installed in an STES and are maintained at 22 °C. Once orbit is attained, the syringe caps are retracted, using a ganging mechanism located on one side of the tray. The ganging mechanism on the other side of the tray then is turned to drive the syringe pistons forward, extruding the protein and precipitant solutions onto the syringe tip. These solutions mix to form a droplet. Water diffuses from the droplet through the vapor space into the more concentrated reservoir solution. As the protein droplet becomes more concentrated, protein crystals grow. At the end of the mission, a crewmember deactivates the experiments by using the ganging mechanism on each VDA-2 tray to draw the drop and crystals back into the syringe.

Protein Crystal Growth Using the Hand-Held Diffusion Test Cells (HHDTCs)

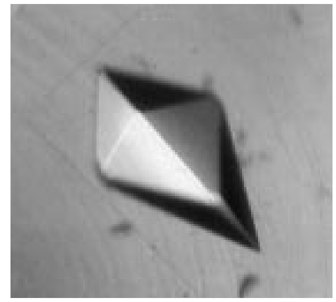
Principal Investigator:
Dr. Alexander McPherson,
University of California, Riverside

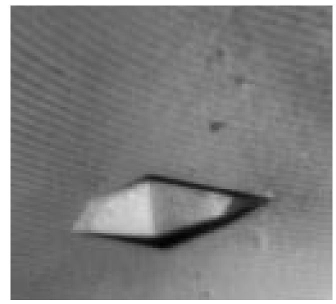
Purpose: to refine the cell design of the Observable Protein Crystal Growth Apparatus (OPCGA) and to characterize proteins and determine the differences that exist in the growth processes of macromolecular crystals in microgravity and on the ground, ultimately optimizing growth procedures and conditions for application in the biochemical field

Importance: The Hand-Held Diffusion Test Cell is demonstration hardware for the cell design of the OPCGA. Optimization of the cell design is important to ensure that crystals can be grown with this cell geometry and that the optics planned for future experiments will observe growing crystals efficiently. At the same time, investigators want to obtain data on the bulk diffusion process to validate ground models. A major goal of this experiment is to improve the design and loading procedures and to eliminate bubble formation, which interferes with crystal growth.

Method: The technique used to grow crystals in the HHDTC is the liquid-liquid diffusion method. A single unit consists of eight cells mounted on a rail and contained within a protective enclosure. Each cell contains three separate volumes with a protein solution, a precipitating solution, and a buffer. The activation of all eight buffer valves within a single enclosure is accomplished simultaneously using a ganging mechanism, which is operated manually by a feedthrough handwheel external to the enclosure. Before activation, a video camera will be focused on the cells to record the liquid-liquid interface as the process begins. A crewmember then will activate the cells by rotating the handwheel. During the MSL-1 mission, three units will be activated and processed within a middeck stowage locker, and one unit will be processed outside the stowage locker to allow video recording of the diffusion process at regular intervals.

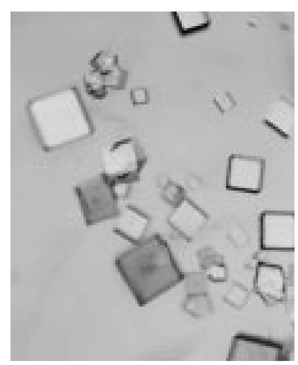
The experiment will provide data on the overall characterization of the proteins, nucleic acids, and viruses in microgravity for comparison with crystals obtained in ground-based laboratories. This flight also will provide a screening of the growth conditions and mixtures in microgravity so that the environment and the solutions for liquid-liquid diffusion protein crystal growth on the OPCGA can be optimized.





The largest crystal grown in microgravity of Vasopressin (top), which has long been associated with cardiovascular function, stands in sharp contrast to an Earth grown crystal (bottom).

This crystal of Factor D, grown aboard USML-1, is the largest crystal ever grown of this morphology, which has been difficult to obtain on Earth. The crystal provided several X-ray diffraction data sets, which contributed significantly to the solution of the 3-dimensional structure of Factor D.



These malic enzyme crystals, grown aboard STS-66, provided the best X-ray diffraction data ever collected for this protein.

HIGH-PACKED DIGITAL TELEVISION (HI-PAC DTV) TECHNICAL DEMONSTRATION

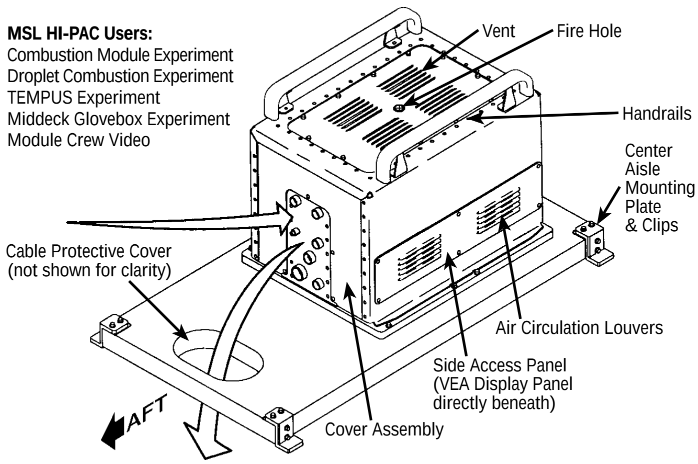
Purpose: to provide multi-channel real-time analog science video from the MSL-1 mission to ground-based investigator teams by means of digital conversion and compression techniques

Importance: The MSL-1 mission will be the second flight for the High-Packed Digital Television, which gives scientists on Earth the ability to view multiple channels of real-time video from the Spacelab module. Until the USML-2 mission, which was the first opportunity for engineers to demonstrate this technology, only one video channel could be transmitted, or downlinked, to the ground from the orbiter. HI-PAC DTV, designed to operate in Spacelab, provides researchers on the ground with up to six channels of real-time video. This capability increases the science return and allows scientists to monitor their experiments, change parameters, and improve the quality and quantity of downlinked data. Also, the ability to downlink video simultaneously from multiple sources moves science data collection into the 21st century.

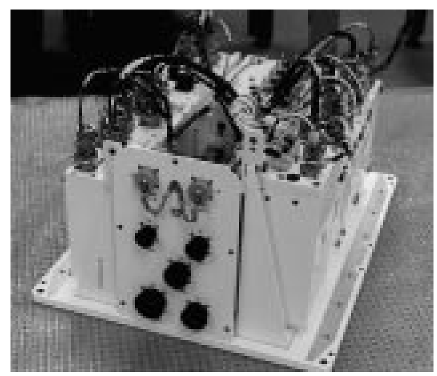
Method: Using experience gained from HI-PAC DTV performance during the USML-2 mission, a second compression technique has been incorporated to provide science data, while using less bandwidth for transmission to the ground. The Motion Pictures Expert Group (MPEG) compression system is an added capability that complements the proven Joint Photographic Expert Group (JPEG) compression technique used during the USML-2 mission in October 1995. The original JPEG compression technique, developed for still-image photography, transforms analog video data into compressed digital data. JPEG was modified to produce motion, M-JPEG, and digitizes each video frame and creates motion by stacking the images as is done for animated video. The M-JPEG technique provides video images with high resolution and good definition of edge detail; however, to achieve smooth motion, M-JPEG requires high data rates of 5 megabits per second or greater.

MPEG, another digital compression technique, was designed specifically for moving images. Unlike M-JPEG, MPEG only digitizes an entire frame at a preset rate of every "nth" frame. Between these complete digitized frames, only the portions of the frame that have changed are updated, allowing MPEG to provide the same quality of motion at significantly lower data rates than M-JPEG. Portions of a scene that do not change are maintained in memory while the system processes the parts of the scene that are changing, and then the two portions are combined and displayed on the video screen. To enhance the quality of the motion from frame to frame, the computer analytically predicts the direction of motion. This prediction routine reduces resolution and compromises fine-edge detail, while maintaining a pleasing image similar to that produced by soft lenses used in portrait photography. The MSL-1 HI-PAC DTV system is using MPEG-1. MPEG-2 and newer versions have not been developed for Spacelab missions.

Even though both M-JPEG and MPEG compress digitized video, different methods are used and both methods have advantages and disadvantages. If edge detail and resolution are desired, then M-JPEG is the better format but requires higher downlink bandwidths. If smooth motion images are required and edge detail and resolution are not essential, the lower data rates and reduced bandwidth offered by MPEG are better. The combination of good motion video and low data rates provided by MPEG allows simultaneous downlink of additional video or more of the higher rate M-JPEG video. With both these techniques, the MSL-1 HI-PAC DTV system provides science teams with six real-time video data streams rather than the single data stream furnished by the standard analog video system.



With the HI-PAC digital television system, up to six channels of real-time video can be downlinked to investigators on the ground.



HI-PAC DTV hardware

The HI-PAC DTV system and experiment video sources are integrated and tested at Kennedy Space Center. This ensures that all of the flight equipment (experiments, module video, HI-PAC, and Spacelab) work properly. Results of this testing often require minor adjustments to be made to optimize the downlinked data.

After Spacelab has been activated, a crewmember will configure the orbiter's closed-circuit television system from the standard analog video to the HI-PAC DTV system. HI-PAC DTV converts standard analog video signals to digital signals then compresses the signals for downlinking through the Spacelab's high rate data system with the other digital science data streams. When the signals are received in the Spacelab Mission Operations Control Center at Marshall Space Flight Center, the digital data are decoded into analog signals. The signals are distributed to the science teams for viewing and recording in the Science Operations Area. When necessary, the Spacelab video system can be switched easily between the standard analog and the HI-PAC DTV systems.

Co-Investigators, Co-Experimenters, and Hardware Developers

Fact Sheet A: Combustion Module-1

Hardware Developer: Mr. Roy Hager, NASA Lewis Research Center

Laminar Soot Processes

Project Scientist: Dr. David Urban, NASA Lewis Research Center

Structure of Flame Balls at Low Lewis-number

Project Scientist: Dr. Karen Weiland, NASA Lewis Research Center

Fact Sheet B: Coarsening in Solid-Liquid Mixtures

Hardware Developer: Mr. John Caruso, NASA Lewis Research Center

Project Scientist: Dr. Thomas Glasgow, NASA Lewis Research Center

Fact Sheet C: Droplet Combustion Experiment

Co-Investigator: Dr. Frederick Dryer, Princeton University

Hardware Developer: Mr. John B. Haggard, NASA Lewis Research Center

Project Scientist: Dr. Vedha Nayagam, Analex Corporation

Fact Sheet D: Expedite the Processing of Experiments to the Space Station (EXPRESS Rack)

Hardware Developer: Ms. Annette Sledd, NASA Marshall Space Flight Center

Physics of Hard Spheres Experiment

Co-Investigators: Dr. William B. Russel, Princeton University
Dr. Ji Xiang Zhu, Princeton University

Hardware Developer: Mr. Michael P. Doherty, NYMA/NASA Lewis Research Center

Project Scientist: Ms. Jerri S. Ling, NASA Lewis Research Center

Astro/PGBA

Co-Investigators: Dr. Andrew Staehlin, University of Colorado
Dr. Peter Wong, Kansas State University
Dr. Yi Li, Kansas State University
Dr. Mark Kliss, NASA Ames Research Center
Dr. Gerard Hyenga, NASA Ames Research Center

Hardware Developer: Dr. Alex Hoehn, BioServe Space Technologies

Project Scientist: Dr. Paul Todd, BioServe Space Technologies

Fact Sheet E: Large Isothermal Furnace

Hardware Developer: Mr. Toshihiko Oida, NASDA

Project Scientist: Japan Dr. Shinichi Yoda, NASDA

Project Scientists: US Dr. Thomas Glasgow and Mr. Alfonso Velosa, NASA Lewis Research Center

Measurement of Diffusion Coefficient by Shear Cell Method

Co-Investigators: Mr. Takehiko Ishikawa, NASDA
Mr. Hirohisa Oda, NASDA
Mr. Toshihiko Oida, NASDA

Diffusion of Liquid Metals and Alloys

Co-Investigator: Dr. Hifumi Tamura, Hitachi Instruments Engineering Co., Ltd.

Diffusion in Liquid Lead-Tin-Telluride

Co-Investigators: Dr. Minoru Kneko, Ishikawajima Jet Service Co., Ltd.
Dr. Toshio Itami, Faculty of Science, Hokkaido University

Impurity Diffusion in Ionic Melts

Co-Investigators: Dr. Yurzuru Sato, Faculty of Engineering, Tohoku University
Dr. Hongmin Zhu, Faculty of Engineering, Tohoku University
Dr. Mamoru Endo, Faculty of Engineering, Tohoku University

Liquid Phase Sintering II

Co-Investigators: Dr. John Johnson, Howmet Corporation
Dr. Shawn Liu, Penn State University

Diffusion Process in Molten Semiconductors

Co-Investigators: Dr. William Arnold, Case Western Reserve University
Dr. Arnon Chait, NASA Lewis Research Center
Professor David Stroud, The Ohio State University

Fact Sheet F: Measuring Microgravity

Space Acceleration Measurement System

Hardware Developer: Mr. Ron Sicker, NASA Lewis Research Center

Project Scientist: Dr. Peter Tschen, NASA Lewis Research Center

Microgravity Measurement Assembly

Hardware Developer: Mr. Maurizio Nati, European Space Agency

Project Scientist: Dr. Hans Hamacher, DLR

Quasi-Steady Acceleration Measurement System

Hardware Developer: Mr. Hans-Ewald Richter, DLR

Project Scientist: Dr. Hans Hamacher, DLR

Orbital Acceleration Research Experiment

Hardware Developer: Mr. William Wagar, NASA Lewis Research Center

Project Scientist: Dr. Peter Tschen, NASA Lewis Research Center

Fact Sheet G: Middeck Glovebox

Hardware Developer: Mr. David Jex, NASA Marshall Space Flight Center

Project Scientist: Dr. Don Reiss, NASA Marshall Space Flight Center

Bubble and Drop Nonlinear Dynamics (BDND)

Co-Investigator: Dr. E.H. Trinh, NASA Jet Propulsion Laboratory

A Study of the Fundamental Operation of a Capillary-driven Heat Transfer (CHT) Device in Microgravity

Co-Investigator: Dr. Jeffrey S. Allen, NASA Lewis Research Center

Internal Flows in a Free Drop (IFFD)

Co-Investigator: Dr. E.H. Trinh, NASA Jet Propulsion Laboratory

Fiber Supported Droplet Combustion

Co-Investigator: Dr. Renato Colantonio, NASA Lewis Research Center

Continued on other side.

Co-Investigators, Co-Experimenters, and Hardware Developers

Fact Sheet H: Electromagnetic Containless Processing Facility (TEMPUS)

Hardware Developer: Mr. Wolfgang Dreier, DARA

Project Scientist: Germany — Dr. Ivan Egry, DLR

Project Scientist: US — Dr. Jan Rogers, NASA Marshall Space Flight Center

Experiments on Nucleation in Different Flow Regimes

Co-Investigators: Dr. William H. Hofmeister, Vanderbilt University
Dr. Michael B. Robinson, Marshall Space Flight Center

Thermophysical Properties of Undercooled Metallic Melts

Co-Investigators: Dr. Georg Lohoefer, DLR
Dr. Berndt Feuerbacher, DLR

Thermophysical Properties of Advanced Materials in the Undercooled Liquid State

Co-Investigator: Dr. Rainer Wunderlich, Technical University Berlin

Measurements of the Surface Tension of Liquid and Undercooled Metallic Alloys by Oscillating Drop Technique

Co-Investigator: Dr. Michael Roesner-Kuhn, Technical University Berlin

Alloy Undercooling Experiments

Co-Investigators: Dr. Douglas Matson, Massachusetts Institute of Technology
Dr. Wolfgang Löser, Institut für Festkoerper und Westoffordchug, Dresden

Study of the Morphological Stability of Growing Dendrites by Comparative Dendrite Velocity Measurements on Pure Ni and a Dilute Ni-C Alloy in the Earth and Space Laboratory

Co-Investigators: Dr. M. Barth, DLR ; Dr. B. Feuerbacher, DLR

Undercooled Melts of Alloys with Polytetrahedral Short-Range Order

Co-Investigators: Dr. Dirk Holland-Moritz, DLR
Dr. Heinrich Bach, University of Bochum
Professor Dr. Hans Fecht, Technical University Berlin
Dr. Kenneth Kelton, Washington University, St. Louis
Professor Dr. Berndt Feuerbacher, DLR

Thermal Expansion of Glass Forming Metallic Alloys in the Undercooled State

Co-Investigators: Dr. B. Damaschke, Institute for Physics, University of Augsburg
Prof. Dr. I. Egry, DLR

AC Calorimetry and Thermophysical Properties of Bulk Glass-Forming Metallic Liquids

Co-Investigator: Dr. David Lee, California Institute of Technology

Measurement of Surface Tension and Viscosity of Undercooled Liquid Metals

Co-Investigator: Dr. Robert Hyers, Massachusetts Institute of Technology

Fact Sheet I: Protein Crystal Growth

Protein Crystal Growth Using the Protein Crystallization Apparatus for Microgravity (PCAM)

Co-Investigators:
Dr. Don Abraham, Medicinal Chemistry, Virginia Commonwealth University
Dr. Gerard J. Bunick, Structural Biology Program, Oak Ridge National Laboratory
Dr. Chong-Hwan Chany, The DuPont Merck Pharmaceutical Company
Dr. Jean-Paul DeClercq, Laboratoire de Chimie Physique et de Cristallographie, Universite Catholique de Louvain, Louvain-la-Neuve, Belgium
Dr. Louis Delbaere, Department of Biochemistry, University of Saskatchewan
Dr. B.W. Dijkstra, Laboratory for Biophysical Chemistry, University of Groningen, The Netherlands
Dr. Drake Egglestow, SmithKline Beecham Pharmaceuticals
Dr. John Helliwell, Chemistry Department, University of Manchester
Dr. Craig Kundrot, Department of Chemistry and Biochemistry, University of Colorado
Dr. John Rosenberg, Department of Crystallography, University of Pittsburg
Dr. William Stallings, Medicinal and Structural Chemistry, Monsanto/Searle Research and Development
Dr. B.C. Wang, Department of Biochemistry and Molecular Biology, University of Georgia
Dr. Mark Wardell, Department of Haematology, University of Cambridge
Dr. Jean-Pierre Wery, Eli Lilly and Co., Lilly Corporate Center
Dr. Daniel Yang, Department of Biochemistry, McMaster University

Hardware Developer: Keith Higginbotham. NASA Marshall Space Flight Center

Project Scientist: Dr. Robert Snyder, NASA Marshall Space Flight Center

Protein Crystal Growth Using the Second Generation Vapor Diffusion Apparatus (VDA-2)

Hardware Developer: Mr. John Nordness, Center for Macromolecular Crystallography

Project Scientist: Ms. Laurel Karr, NASA Marshall Space Flight Center

Protein Crystal Growth Using the Hand-Held Diffusion Test Cells (HHDTC)

Hardware Developer: Mr. Ron King, NASA Marshall Space Flight Center

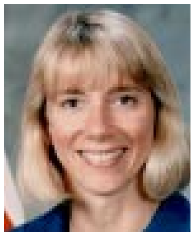
Project Scientist: Mr. Bill Witherow, NASA Marshall Space Flight Center

NASA's

Microgravity Science Laboratory:

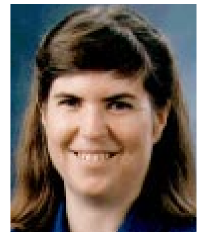
Illuminating the Future

James D. Halsell, Jr., Commander
Lieutenant Colonel James Donald Halsell, Jr., (USAF) earned his Bachelor of Science degree in Engineering from the United States Air Force Academy in 1978, a Master of Science degree in Management from Troy University in 1983, and a Master of Science degree in Space Operations from the Air Force Institute of Technology in 1985. He has served as an F4-D aircraft commander and his graduate thesis, sponsored by the Johnson Space Center Crew Systems Division, prototyped a space rescue transfer vehicle using off-the-shelf equipment. He served as the pilot on STS-65, the Second International Microgravity Laboratory mission in July 1994 and as the pilot on STS-74, the second Space Shuttle mission to rendezvous and dock with the Russian Space Station MIR.



Susan Leigh Still, Pilot
Lieutenant Commander Susan Leigh Still (USN) received her Bachelor of Science degree in Aeronautical Engineering from Embry-Riddle University in 1982 and a Master of Science degree in Aerospace Engineering from the Georgia Institute of Technology in 1985. She is a Distinguished Naval Graduate of the Aviation Officer Candidate School and a Distinguished Graduate of the United States Naval Test Pilot School, and she has been awarded the Navy Commendation Medal, the Navy Achievement Medal, and the National Defense Service Medal. Still has more than 2,000 flight hours in more than 30 types of aircraft. MSL-1 will be her first spaceflight.

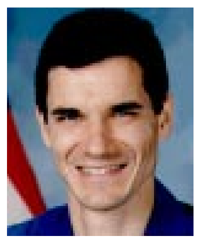
Dr. Michael L. Gernhardt, Ph.D., Mission Specialist
Dr. Michael Gernhardt received a Bachelor of Science degree in Physics from Vanderbilt University in 1978 and Master of Science and Doctor of Philosophy degrees in Bioengineering from the University of Pennsylvania in 1983 and 1991, respectively. Before joining NASA in 1992, Dr. Gernhardt worked as a professional deep-sea diver and developed sub-sea robotics equipment and new astronaut- and robot-compatible tools for Space Station maintenance, as well as portable life support systems and decompression procedures for extravehicular activity. After becoming an astronaut, he was a Mission Specialist on STS-69, during which he performed a spacewalk to evaluate future Space Station tools and hardware. Dr. Gernhardt will serve as Flight Engineer on the MSL-1 mission.



Dr. Janice Voss, Ph.D., Payload Commander
Dr. Janice Voss received her Bachelor of Science degree in Engineering Science from Purdue University in 1975 and a Master of Science degree in Electrical Engineering and a Doctorate in Aeronautics and Astronautics from the Massachusetts Institute of Technology in 1977 and 1987, respectively. Dr. Voss first flew on STS-57 in 1993, a mission to capture and return the European Retrievable Carrier (EURECA). More recently, she flew on STS-63, which rendezvoused with the Russian Space Station MIR and deployed and retrieved SPARTAN 204. Dr. Voss has logged more than 438 hours in space and will be the Payload Commander for MSL-1.

Dr. Donald A. Thomas, Ph.D., Mission Specialist
Dr. Donald Thomas graduated with Honors and a Bachelor of Science degree in Physics from Case Western Reserve University in 1977. He received a Master of Science degree and a Doctorate in Materials Science from Cornell University in 1980 and 1982, respectively, after which he joined AT&T Bell Laboratories to develop advanced materials and processes for high-density interconnections of semiconductor devices. He was a Principal Investigator for the Microgravity Disturbances Experiment, a middeck crystal growth experiment that flew on STS-32 in 1990, investigating the effects of orbiter- and crew-induced disturbances on the growth of crystals in space. Dr. Thomas became an astronaut in 1991 and flew as a Mission Specialist on STS-65 in 1994 and on STS-70 in 1995.

Dr. Roger K. Crouch, Ph.D., Payload Specialist
Dr. Roger Crouch earned a Bachelor of Science in Physics from Tennessee Polytechnic Institute in 1958 and a Master of Science in Physics and a Doctor of Philosophy from Virginia Polytechnic Institute in 1968 and 1971, respectively. As Chief Scientist of NASA's Microgravity Science and Applications Division (MSAD) since 1985, he has been the manager for a research program supporting materials science, fluid physics, low-temperature microgravity physics, combustion science, and biotechnology. He served as Program Scientist for the Spacelab J, First and Second International Microgravity Laboratory, and First United States Microgravity Laboratory missions.
In addition, Dr. Crouch trained as the Alternate Payload Specialist on STS-42.



Dr. Gregory Linteris, Ph.D., Payload Specialist
Dr. Greg Linteris received a Bachelor of Science degree with Honors in Chemical Engineering from Princeton University in 1979, a Master of Science degree from the Design Division of the Mechanical Engineering Department at Stanford University in 1984, and a Doctorate in Mechanical and Aerospace Engineering from Princeton in 1990. Since 1992, he has been at the National Institute of Standards and Technology, where he has been developing a research program on advanced fire suppressants and studying the restraining mechanisms of chemical inhibitors.

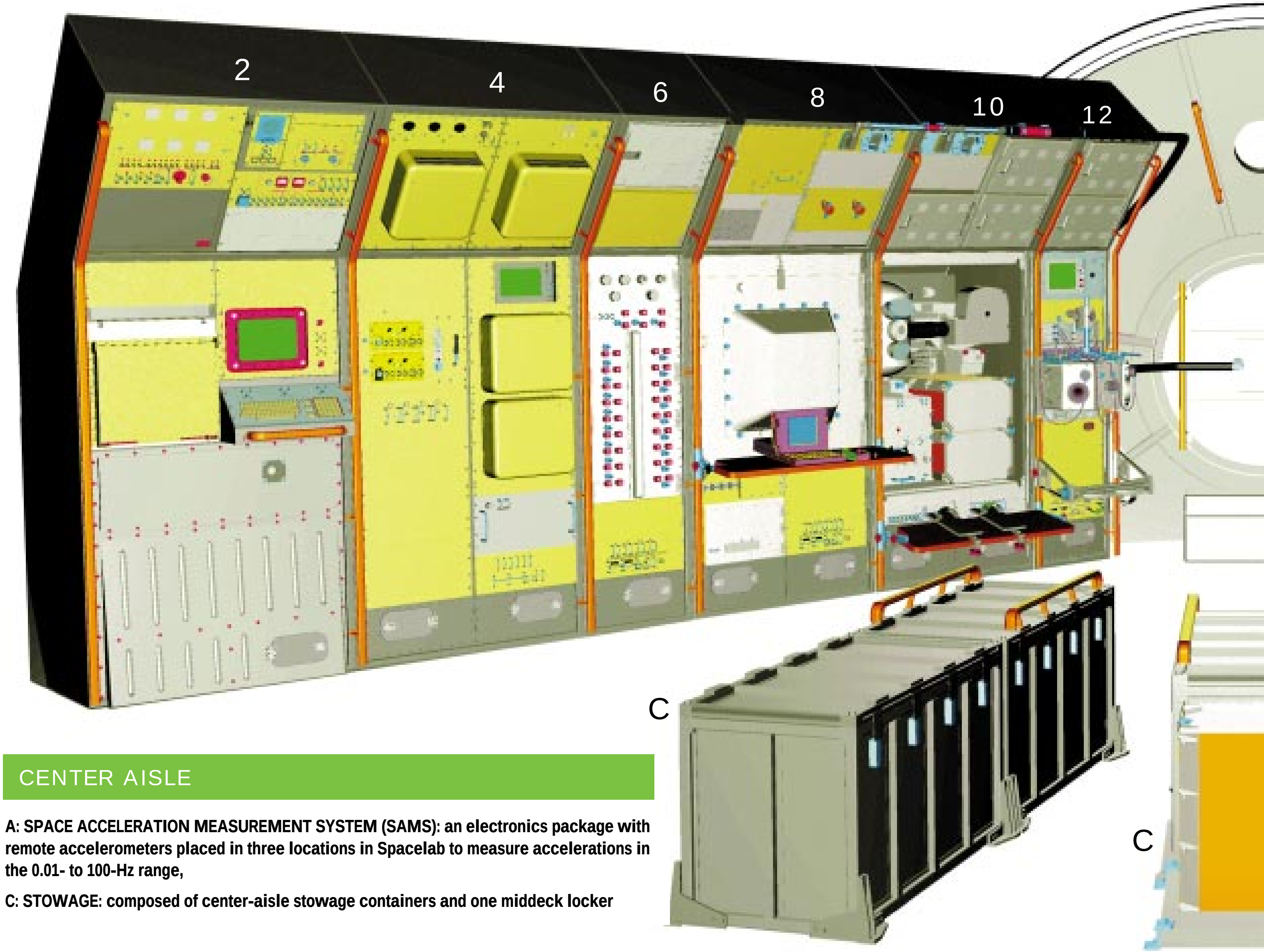
Dr. Paul D. Ronney, Sc.D., Payload Specialist
Dr. Paul Ronney received a Bachelor of Science degree in Mechanical Engineering from the University of California, Berkeley in 1978, a Master of Science in Aeronautics from the California Institute of Technology in 1979, and a Doctor of Science in Aeronautics and Astronautics in 1983 from the Massachusetts Institute of Technology. Dr. Ronney has been at the University of Southern California since 1993, where he currently holds a joint appointment as an Associate Professor in the Departments of Mechanical and Aerospace Engineering. He is Principal Investigator for the Structure of Flame Balls at Low Lewis-number (SOFBALL) experiment, which will be part of the MSL-1 payload.

MSL-1 Management

Program Manager:	Mr. James McGuire, NASA Headquarters
Program Scientist:	Dr. Mark Lee, NASA Headquarters
Mission Manager:	Ms. Teresa B. Vanhooser, NASA MSFC
Assistant Mission Manager:	Mr. Randy K. McClendon, NASA MSFC
Mission Scientist:	Dr. Michael B. Robinson, NASA MSFC
Assistant Mission Scientist:	Dr. James Patton Downey, NASA MSFC
Chief Engineer:	Mr. Allen S. Bacskay, NASA MSFC
Payload Operations Director:	Mr. Robert P. Little, NASA MSFC

**For More Information, Contact:
Public Affairs Office
National Aeronautics and Space Administration
Washington, DC 20546**

MSL-1 RACK CO



CENTER AISLE

A: SPACE ACCELERATION MEASUREMENT SYSTEM (SAMS): an electronics package with remote accelerometers placed in three locations in Spacelab to measure accelerations in the 0.01- to 100-Hz range,

C: STOWAGE: composed of center-aisle stowage containers and one middeck locker

STARBOARD SIDE

Rack 2

CONTROL CENTER: houses the Payload General Support Computer, intercom, and the High Data Rate recorder, as well as monitors for managing data and for operating laboratory systems and certain experiments

Rack 4

STANDARD SPACELAB SUBSYSTEMS: contains a fluid loop pump that supports experiment cooling, video recorders that support all payload data, and an experiment heat exchanger

Rack 6

CM-1 FLUID SUPPORT PACKAGE: contains the Video Cassette Recorder package and the Fluid Supply Package for the Combustion Module-1

Rack 8

COMBUSTION MODULE-1 (CM-1): a facility that accommodates a variety of combustion experiments through the use of experiment-unique chamber inserts

Rack 10

DROP COMBUSTION EXPERIMENT (DCE) APPARATUS: an enclosed chamber in which helium-oxygen fuel mixtures are injected and single droplets are burned

Rack 12

MIDDECK GLOVEBOX (MGBX): a facility that provides a sealed work area, offering a clean working space and minimizing contamination risks to Spacelab and to experiment samples

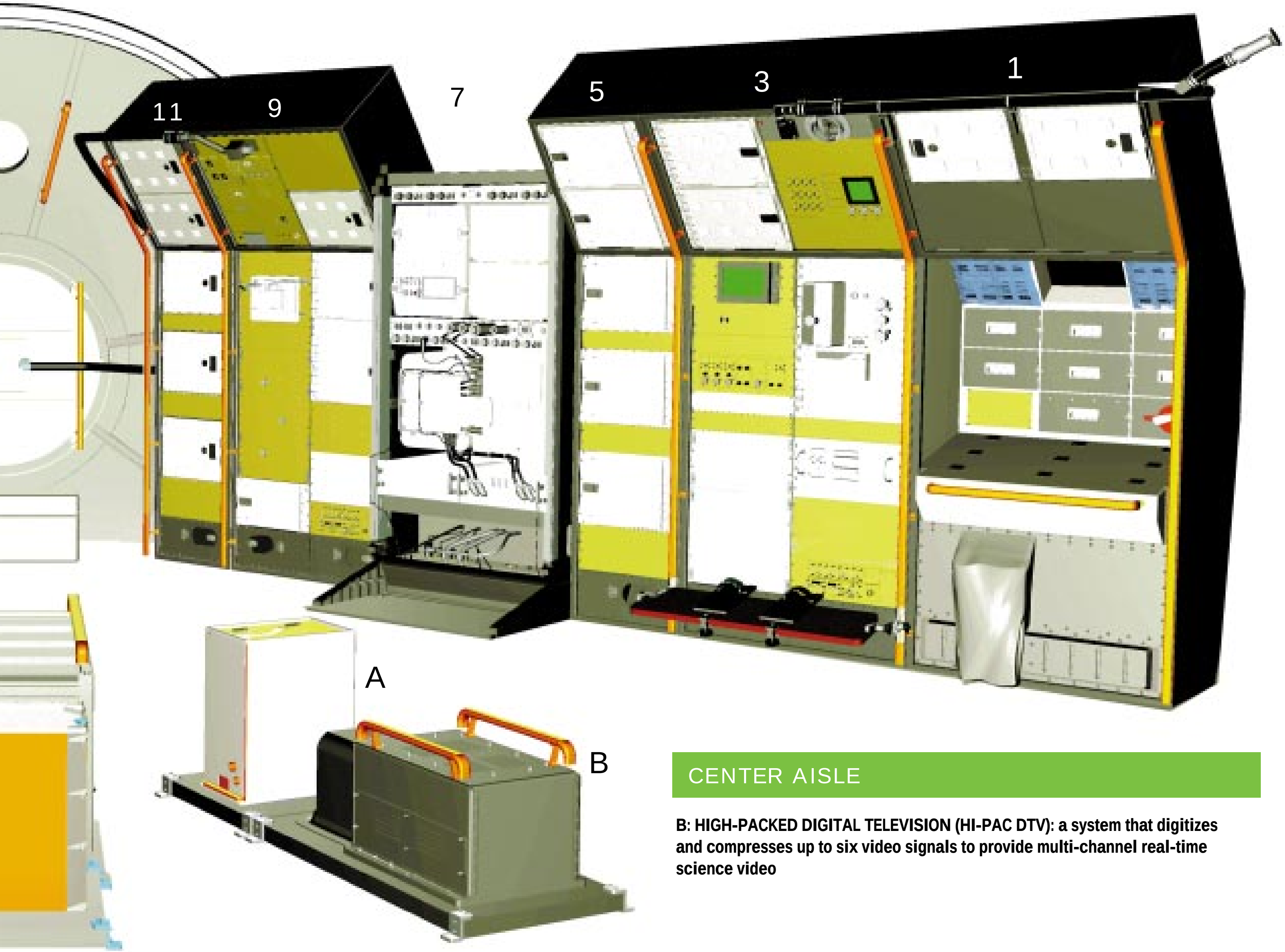
MIDDECK EXPERIMENTS

PROTEIN CRYSTAL GROWTH WITH THE PROTEIN CRYSTALLIZATION APPARATUS FOR MICROGRAVITY (PCAM)

SECOND GENERATION VAPOR DIFFUSION APPARATUS (VDA-2)

HAND-HELD DIFFUSION TEST CELLS (HHDTCs)

ONFIGURATION



CENTER AISLE

B: HIGH-PACKED DIGITAL TELEVISION (HI-PAC DTV): a system that digitizes and compresses up to six video signals to provide multi-channel real-time science video

PORT SIDE

Rack 11

STOWAGE: areas where experiment equipment and samples are stored

Rack 9

LARGE ISOTHERMAL FURNACE (LIF): a vacuum-heating furnace designed to heat large samples uniformly.

Rack 7

EXPRESS RACK ASTRO/PLANT GENERIC BIOPROCESSING APPARATUS (Astro/PGBA): a facility equipped with fluorescent lighting and an atmospheric control system, which supports plant growth for commercial research; mounted in the middeck for launch and landing

PHYSICS OF HARD SPHERES EXPERIMENT (PHaSE): allows scientists to investigate the behavior and physical properties of hard colloidal spheres

Rack 5

STOWAGE: areas where experiment equipment and samples are stored

Rack 3

ELECTROMAGNETIC CONTAINERLESS PROCESSING FACILITY (TEMPUS): an electromagnetic levitation facility that allows containerless processing of metallic samples

MICROGRAVITY MEASUREMENT ASSEMBLY (MMA): a microgravity monitoring system capable of providing real-time display of accelerations detected by seven sensor heads that measure accelerations in the 0.1- to 100-Hz range in three axes.

QUASI-STEADY ACCELERATION MEASUREMENT (QSAM) SYSTEM: an instrument with four rotating sensors designed to detect steady, very low-frequency, residual accelerations between 0 and 0.02 Hz within Spacelab. An additional package with three stationary sensors has an upper bandwidth of 50 Hz.

Rack 1

WORKBENCH: an area equipped with stowage containers, tools, and small equipment for carrying out general activities, such as recording data in logs or preparing for an experiment